# BASIC MACHINES

BASIC

NAVY TRAINING COURSES

NAVPERS 10624

# BASIC MACHINES

PREPARED BY
STANDARDS AND CURRICULUM DIVISION
TRAINING
BUREAU OF NAVAL PERSONNEL



NAVY TRAINING COURSES
EDITION OF 1946

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1946

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - Price 35 cents

# PREFACE

This book is prepared as a basic reference for those enlisted men of the Navy whose duties require them to have a knowledge of the fundamentals of machinery.

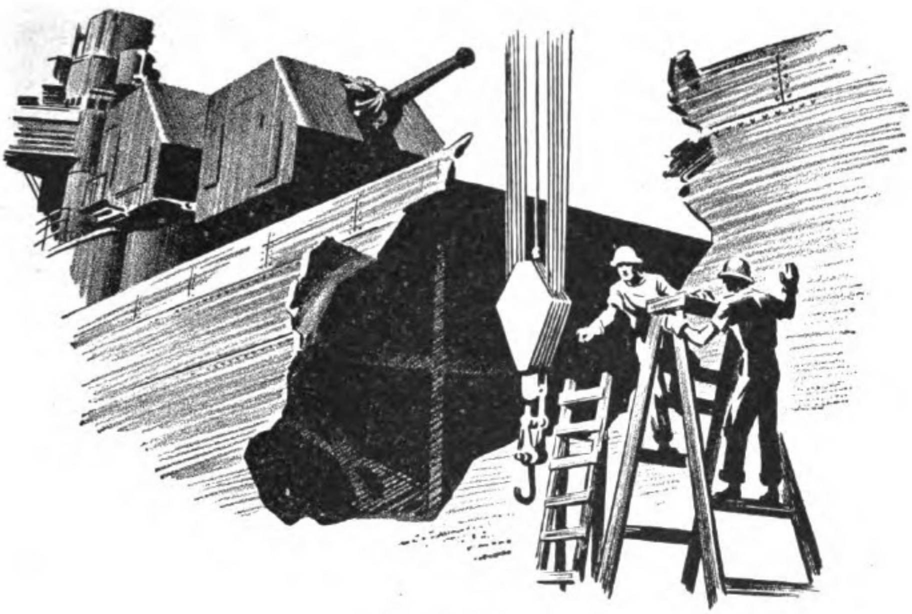
This knowledge is of especial importance to those men in the Seamen Branch, Artificer Branch, and Engine Room Force who are responsible for the operation, maintenance, and repair of mechanical equipment. Whether the job involves work on steering gear, deck machinery, or engines, the technician should be thoroughly familiar with the basic principles underlying the operation of the mechanisms.

Beginning with the simplest machines—the lever—the book proceeds with a discussion of block and tackle, wheel and axle, incline plane, screw, and gears. It explains the principles of work and power, and differentiates between the terms force and pressure. The fundamentals of hydrostatic and hydraulic mechanisms are discussed in detail. The final chapter includes several examples of the combinations of simple mechanisms which make complex machines.

As one of several basic NAVY TRAINING COURSES, this book was prepared in the Training Courses Section, Standards and Curriculum Division, Training, Bureau of Naval Personnel.

# TABLE OF CONTENTS

# BASIC MACHINES



## CHAPTER 1

# SIMPLEST MACHINE

### SMOOTH OPERATION

When the big battlewagon opens up with all three turrets, those nine terrific blasts shake the whole ship and she slides sideways in the water. But 20 miles away, more than ten tons of TNT armor-piercing steel crash into the enemy.

Meanwhile, with perfect rhythm the gun crews get more shells up on the hoist, ram them into breeches, and supply the powder bags. They slam the breech plugs, report the guns ready, and flash the word to the fire-control tower. The guns roar again.

But now YOUR ship is hit, and the damage-control crew goes into action. A fire is put out, broken pipe lines are mended, and the hull is kept watertight. A jury rig is fitted to take over for the damaged steering engines, and the battleship retains its place on the battle line.

After all is quiet and the crippled ship has returned to port with the starboard bulkhead ripped away, another gang takes over for repair. Dockside cranes and switch engines move about, rivet guns clatter and bang, and torches burn off paint and cut metal amidst pungent smells.

Mechanical devices have been used in these jobs. But these superb machines will function only when the crews know how to use them. No mechanical device is better than the men who use it. Today, as in the days of John Paul Jones, the Nation's fate rests with the MEN aboard the Navy's ships.

## WHAT IS A MACHINE?

Your Navy is one-hundred-percent mechanized. Aboard ship or ashore you'll make daily use of machines. Some of them are simple, some are complicated; some are familiar, and others are unlike any you have seen before.

Ordinarily you think of a MACHINE as some complex device—a gasoline engine or a typewriter. They ARE machines, but so is a hammer, a screwdriver, a ship's wheel. A MACHINE IS ANY DEVICE THAT HELPS YOU TO DO WORK. It may help by changing the amount of the force or the speed of action. For example, a claw hammer is a machine—you can use it to apply a large force for pulling out a nail. A relatively small pull on the handle produces a much greater force at the claws.

There are only six SIMPLE MACHINES—the LEVER, the BLOCK, the WHEEL and AXLE, the INCLINED PLANE, the SCREW, and the GEAR. When you are familiar with the principles of these simple machines, you can readily understand the operation of complex machines. COMPLEX MACHINES are merely COMBINATIONS of TWO OR MORE SIMPLE MACHINES.

## LEVERS

The simplest machine, and perhaps the one with which you are most familiar, is the LEVER. When you row a boat, you are applying the principle of the lever. A wheelbarrow is a lever, and so is your arm.

There are three basic parts which you find in the oar, the wheelbarrow, or your arm—in all levers. Look at the lever in figure 1. You see a pivotal

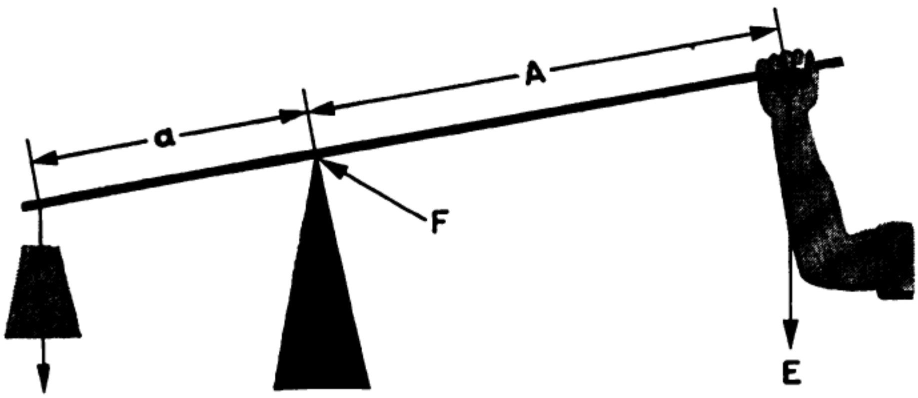



Figure 1.—A simple lever.

point $F$ called a FULCRUM; a force or EFFORT $E$, which you apply at a DISTANCE $A$ from the fulcrum; a RESISTANCE $R$ which acts at a DISTANCE $a$ from the fulcrum. Distances $A$ and $a$ are the LEVER ARMS.

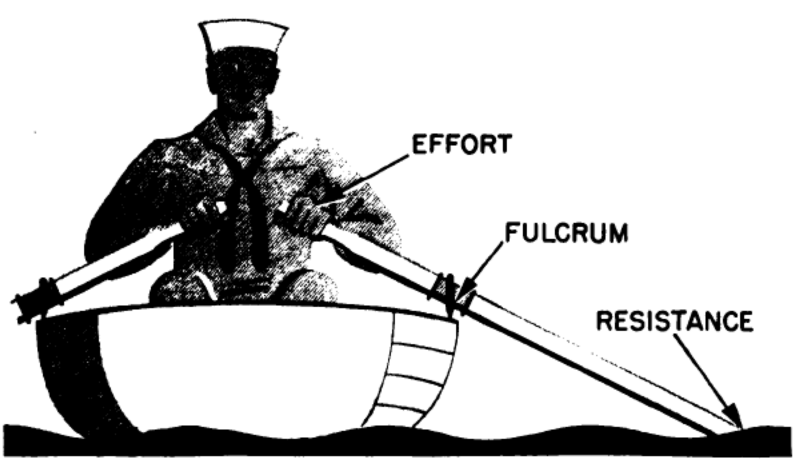



Figure 2.—Oars are levers.

Notice that the sailor in figure 2 applies his effort on the handles of the oars. The oarlock acts as the fulcrum, and the water acts as the resistance to be overcome. In this case—as in figure 1—the force is applied on one side of the fulcrum and the resistance to be overcome is applied on the opposite side. You call this type a FIRST-CLASS LEVER. With this class of lever the directions of the applied effort and the force against the resistance are opposite—that is, you move one end of the lever in one direction and the other end of the lever moves in the opposite direction.

There are also two other classes of levers—SECOND-CLASS and THIRD-CLASS LEVERS. The SECOND-CLASS LEVER is illustrated by the wheelbarrow in figure 3.

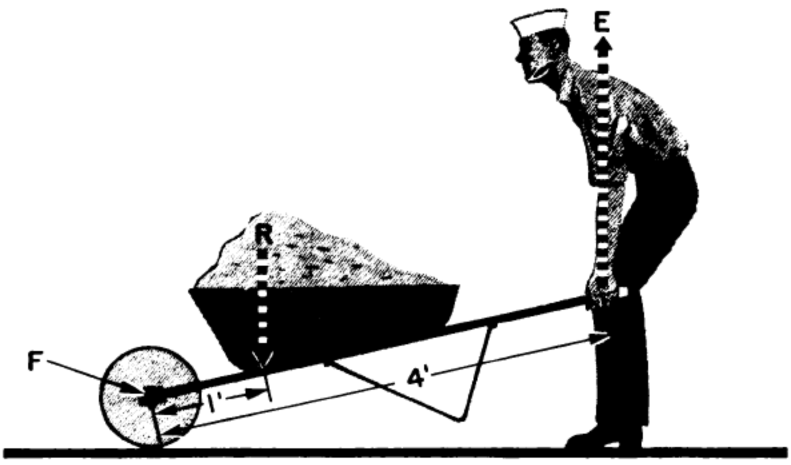



Figure 3.—This makes it easier.

In this class, the resistance to be overcome is located between the fulcrum and the point where the effort is applied—while the direction of the applied effort and the force against the resistance are the same as for a FIRST-CLASS LEVER. You pull up when you want to raise a load.

Both first-class and second-class levers are commonly used to help in overcoming big resistances with a relatively small effort. You know that you can carry a much bigger load on a wheelbarrow than without one. For example, by pulling upward on the handles of the wheelbarrow with a force of about 50 pounds, you can lift a load of sand weighing perhaps 200 pounds. However, you don't always use the first-class lever to magnify your effort. Sometimes, as with an oar, it gives you a convenient method of APPLYING the effort. You PULL the oar handle toward you in order to PUSH the blade in the opposite direction against the water.

There are occasions, however, when you'll want to speed up the movement of the resistance even though you have to use a large amount of effort.

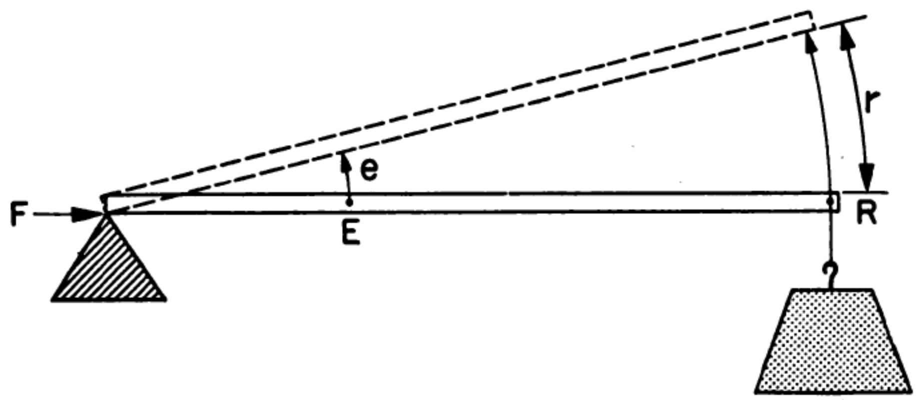



Figure 4.—A third-class lever.

Levers that help you to accomplish this are called THIRD-CLASS LEVERS. You can always spot them because you will find the effort applied BETWEEN the fulcrum and the resistance. But here again—as with the second-class lever—you pull up to raise a load.

Look at figure 4. It is easy to see that while point $E$ is moving the short distance $e$, the resistance $R$ has been moved a greater distance $r$. The speed of $R$ must have been greater than that of $E$, since $R$ covered a greater distance in the small length of time.

Now look at figure 5. Your arm is a THIRD-CLASS LEVER. Incidentally, it is this lever action that makes it possible for you to flex your arms so quickly. Your elbow is the fulcrum. Your biceps muscle which ties onto your forearm about an inch below the elbow applies the effort; and your hand is the resistance, located some 18 inches from the fulcrum. In the split second it takes your biceps muscle to contract an inch, your hand has moved through an 18-inch arc. But, you know from experience that it takes a big pull at *E* to overcome a relatively small resistance at *R*. Just to remind yourself of this principle, try closing a door by pushing on it about

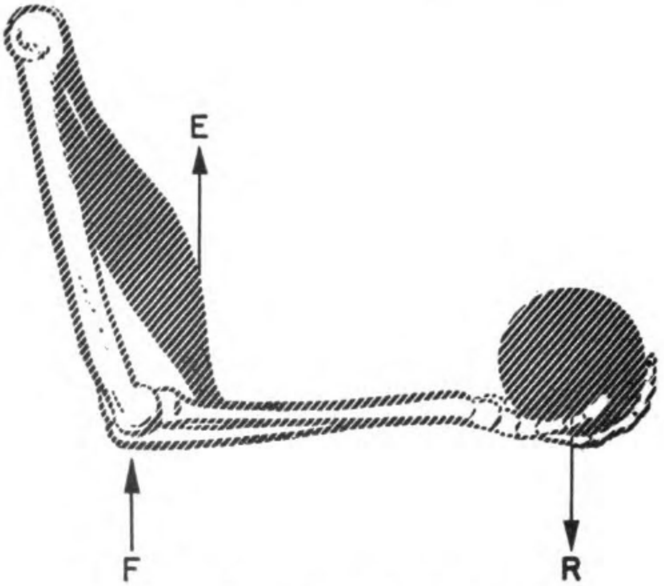



**Figure 5.—Your arm is a lever.**

three or four inches from the hinges—or fulcrum. The moral is—you don't use third-class levers to do heavy jobs—you use them to gain speed.

## LEVER ARMS

One convenient thing about machines is that you can determine IN ADVANCE the forces required for their operation, as well as the forces they will exert. Consider for a moment the first-class lever. Suppose you have an iron bar, like the one shown in figure 6. This bar is 9 feet long, and you want to use it to raise a 300-pound crate off the deck while you slide a dolly under the crate. But, you can exert only 100 pounds to lift the crate. So, you place the fulcrum—a wooden block—beneath one end of the bar, and force that end of the bar under the crate. Then you push down on the other end of the bar. After a few adjustments of the position of the fulcrum, you will find that your 100-pound force will just lift the crate when the fulcrum is 2 feet from center of the crate.

This leaves a 6-foot length of bar from the fulcrum to the point where you push down. The 6-foot portion is THREE times as long as the fulcrum to the center of the crate. But you lifted a load three times as great as the force you applied—$3 \times 100 = 300$ pounds. Here is an indication of a direct relation-

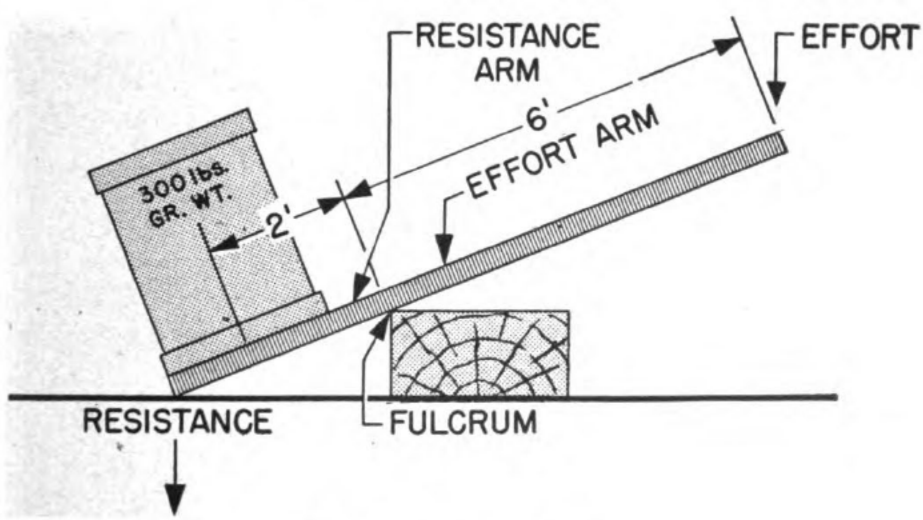



**Figure 6.—Easy does it.**

ship between lengths of lever arms and forces acting on those arms.

You can state this relationship in general terms by saying—THE LENGTH OF THE EFFORT ARM IS THE SAME NUMBER OF TIMES GREATER THAN THE LENGTH OF THE RESISTANCE ARM AS THE RESISTANCE TO BE OVERCOME IS GREATER THAN THE EFFORT YOU MUST APPLY. Writing these words as a mathematical equation, it looks like this—

$$\frac{L}{l}=\frac{R}{E}$$

in which,

$L$ = length of effort arm.
$l$ = length of resistance arm.
$R$ = resistance weight or force.
$E$ = effort force.

Remember that all distances must be in the SAME UNITS—such as feet, and all forces must be in the same units—such as pounds.

Now take another problem and see how it works out. Suppose you want to pry up the lid of a paint can with a 6-inch file scraper, and you know that the average force holding the lid is 50 pounds. If

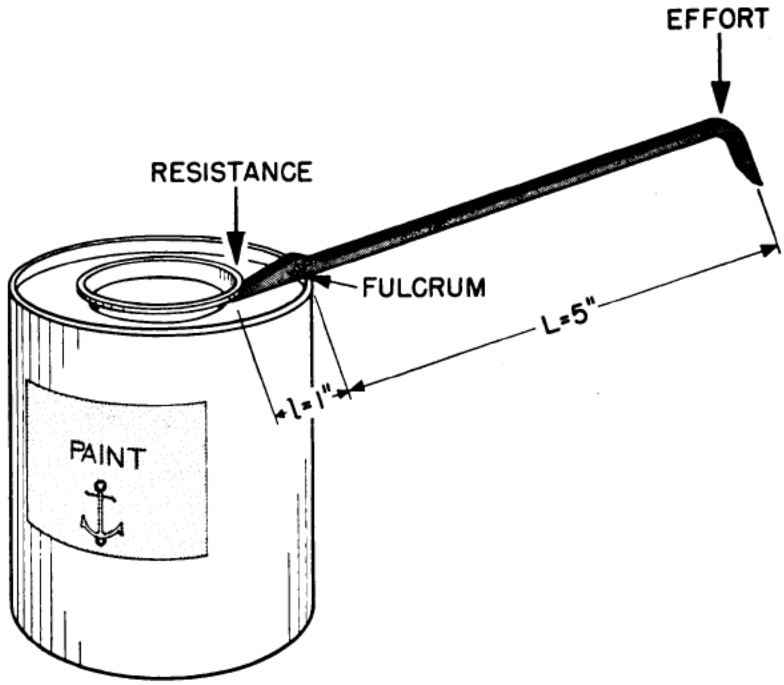



Figure 7.—A first-class job.

the distance from the edge of the paint can to the edge of the cover is one inch, what force will you have to apply on the end of the file scraper?

According to the formula:

$$\frac{L}{l}=\frac{R}{E}$$

Here $L=5$ inches; $l=1$ inch; $R=50$ pounds, and $E$ is unknown.

Substitute the numbers in their proper places, Then,

$$\frac{5}{1}=\frac{50}{E}$$

and

$$E=\frac{50\times 1}{5}=10 \text{ pounds}$$

You will need to apply a force of only 10 pounds.

The same general formula applies for SECOND-CLASS LEVERS. But you must be careful to measure the PROPER LENGTHS of the effort arm and the resistance arm. Looking back at the wheelbarrow problem, assume that the length of the handles from the axle of the wheel—which is the fulcrum—to the grip is 4 feet. How long is the EFFORT ARM? You're right, it's 4 feet. If the center of the load of sand is 1 foot from the axle, then the length of the RESISTANCE ARM is 1 foot.

By substituting in the formula,

$$\frac{L}{l}=\frac{R}{E}$$

$$\frac{4}{1}=\frac{200}{E}$$

and $$E=50 \text{ lb.}$$

Now for the THIRD-CLASS LEVER. With one hand, you lift a projectile weighing approximately 100 pounds. If your biceps muscle attaches to your forearm 1 inch below your elbow, and the distance from the elbow to the palm of your hand is 18 inches, what pull must your muscle exert in order to hold the projectile and flex your arm at the elbow?

By substituting in the formula,

$$\frac{L}{l}=\frac{R}{E}, \text{ it becomes } \frac{1}{18}=\frac{100}{E}$$

and $$E=18\times 100=1{,}800 \text{ lb.}$$

Your muscle must exert an 1,800-pound pull to hold up a 100-pound shell. Our muscles are poorly arranged for lifting or pulling—and that's why some work seems pretty tough. But REMEMBER, THIRD-CLASS LEVERS are used primarily to SPEED UP the MOTION of the resistance.

You will find some more problems and answers at the end of the book. Try them for practice.

## IT'S YOUR ADVANTAGE

There is another thing about first-class and second-class levers that you have probably noticed by now. Since they can be used to MAGNIFY the applied force, they provide POSITIVE MECHANICAL ADVANTAGES. The third-class lever provides what's called a FRACTIONAL MECHANICAL ADVANTAGE, which is really a mechanical DISADVANTAGE—you use more force than the force of the load you lift.

In the wheelbarrow problem, you saw that a 50-pound pull actually overcame the 200-pound weight of the sand. The sailor's effort was magnified four times, so you may say that the MECHANICAL ADVANTAGE of the wheelbarrow is 4. Expressing the same idea in mathematical terms,

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{RESISTANCE}}{\text{EFFORT}}$$

or

$$M.\ A. = \frac{R}{E}$$

Thus, in the case of the wheelbarrow, $M.\,A. = \frac{200}{50} = 4$

THIS RULE APPLIES TO ALL MACHINES.

Mechanical advantage of levers may also be found by dividing the length of the effort arm $A$ by the length of the resistance arm $a$. Stated as a formula, this reads:

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{EFFORT ARM}}{\text{RESISTANCE ARM}}$$

or

$$M.\ A. = \frac{A}{a}$$

How does this apply to third-class levers? Your muscle pulls with a force of 1,800 pounds in order to lift a 100-pound projectile. So you have a mechanical advantage of $\frac{100}{1,800}$, or $\frac{1}{18}$, which is fractional—less than 1.

## CURVED LEVER ARMS

Up to this point you have been looking at levers with STRAIGHT ARMS. In every case, the direction in which the resistance acts is parallel to the direction

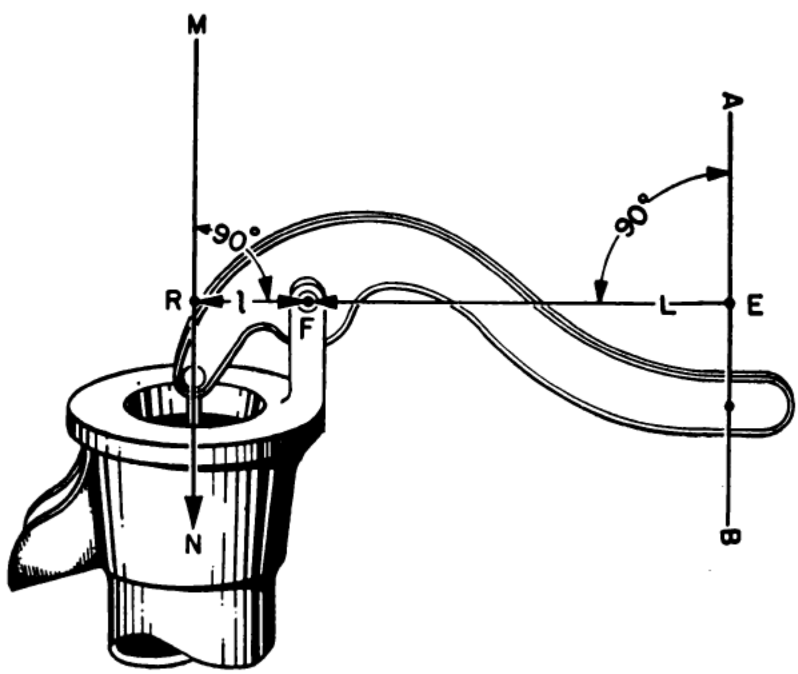



Figure 8.—A curved lever arm.

in which the effort is exerted. However, all levers are not straight. You'll need to learn to recognize all types of levers, and to understand their operation.

Look at figure 8. You may wonder how to

measure the LENGTH of the effort arm, which is represented by the curved pump handle. You do NOT measure around the curve—you still use a straight-line distance. To determine the length of the effort arm, draw a straight line *AB* through the point where the EFFORT is applied and in the direction that it is applied. From point *E* on this line, draw a second line *EF* that passes through the FULCRUM and is perpendicular to line *AB*. The length of the line *EF* is the actual length *L* of the EFFORT ARM.

To find the length of the RESISTANCE ARM, use the same method. Draw a line *MN* in the direction that the resistance is operating, and through the point where the resistance is attached to the other end of the handle. From point *R* on this line, draw a line *RF* perpendicular to *MN* so that it passes through the fulcrum. The length of *RF* is the length *l* of the RESISTANCE ARM.

Regardless of the curvature of the handle, this method can be used to find the lengths *L* and *l*. Then curved levers are solved just like straight levers.

Now, for a quick review of levers.

LEVERS ARE MACHINES because they help you to do your work. They help by changing the size, direction, or speed of the force you apply.

There are THREE CLASSES OF LEVERS. They differ primarily in the relative points where effort is applied, where the resistance is overcome, and where the fulcrum is located.

FIRST-CLASS LEVERS have the EFFORT and the RESISTANCE on OPPOSITE SIDES of the FULCRUM—and effort and resistance move in OPPOSITE DIRECTIONS.

SECOND-CLASS LEVERS have the EFFORT and the RESISTANCE on the SAME SIDE of the fulcrum, but the EFFORT is FARTHER from the FULCRUM than is the RESISTANCE. Both effort and resistance move in the SAME direction.

THIRD-CLASS LEVERS have the EFFORT applied on the SAME side of the FULCRUM as the RESISTANCE, but the effort is applied BETWEEN THE RESISTANCE AND THE FULCRUM. Both move in the SAME direction.

First-class and second-class levers can be used to magnify the amount of the effort exerted, and to decrease the speed of the effort. First-class and third-class levers can be used to magnify the distance and the speed of the effort exerted, and to decrease its magnitude.

The same general formula applies for all three types—

$$\frac{L}{l}=\frac{R}{E}$$

MECHANICAL ADVANTAGE—M. A.—is an expression of the ratio of the applied force and the resistance. It may be written—

$$M.\ A.=\frac{R}{E}$$

## APPLICATIONS AFLOAT AND ASHORE

Doors aboard a ship are locked shut by lugs called DOGS. Figure 9 shows you how these dogs are used to secure the door. If the handle is four times as long as the lug, that 50-pound heave of yours is multiplied to 200 pounds against the slanting face of the wedge. Incidentally, take a look at that wedge—it's an INCLINED PLANE, and it multiplies the 200-pound force by about four. Result—your 50-pound heave actually ends up as an 800-pound force on each wedge to keep the hatch closed! The hatch dog is one use of a first-class lever, in combination with an inclined plane.

The BREECH of a big gun is closed with a breech plug. Figure 10 shows you that this plug has some interrupted screw threads on it which fit into similar interrupted threads in the breech. Turning the plug

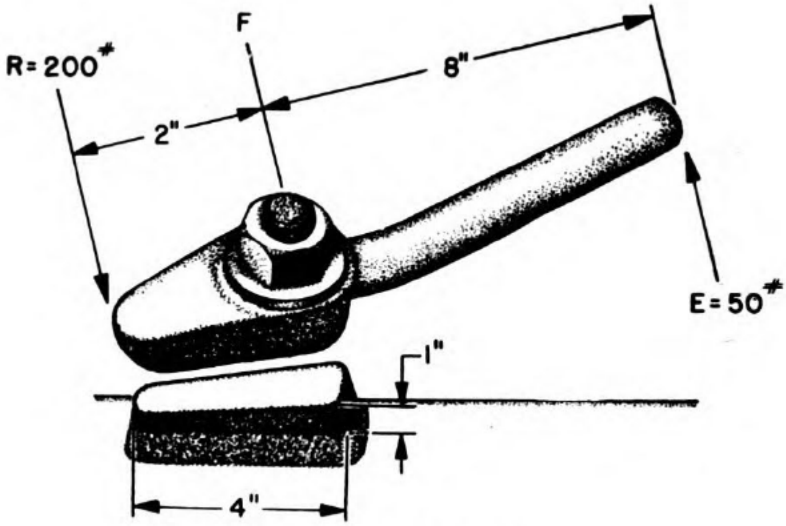



**Figure 9.—It's a dog.**

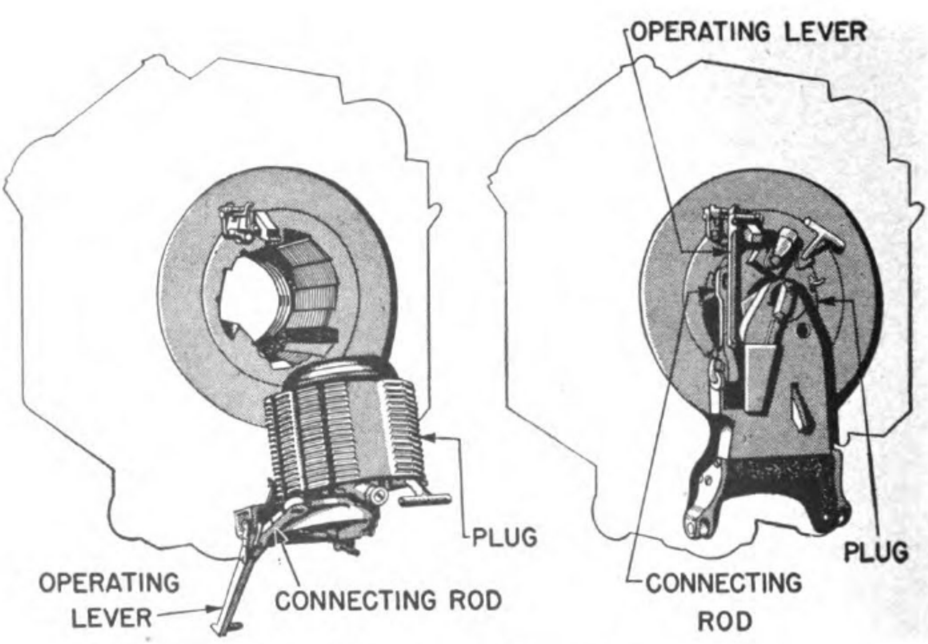



**Figure 10.—A 16-incher's breech.**

part way around locks it into the breech. The plug is locked and unlocked by the operating lever. Notice that the connecting rod is secured to the operating lever a few inches from the fulcrum. You'll see that this is an application of a second-class lever!

You know that the plug is in there good and tight. But, with a mechanical advantage of ten, your 100-pound pull on the handle will twist the plug loose with a force of a half-ton.

If you've spent any time opening crates at a base, you've already used a WRECKING BAR. The bluejacket in figure 11 is busily engaged in tearing that crate open. The wrecking bar is a first-class lever.

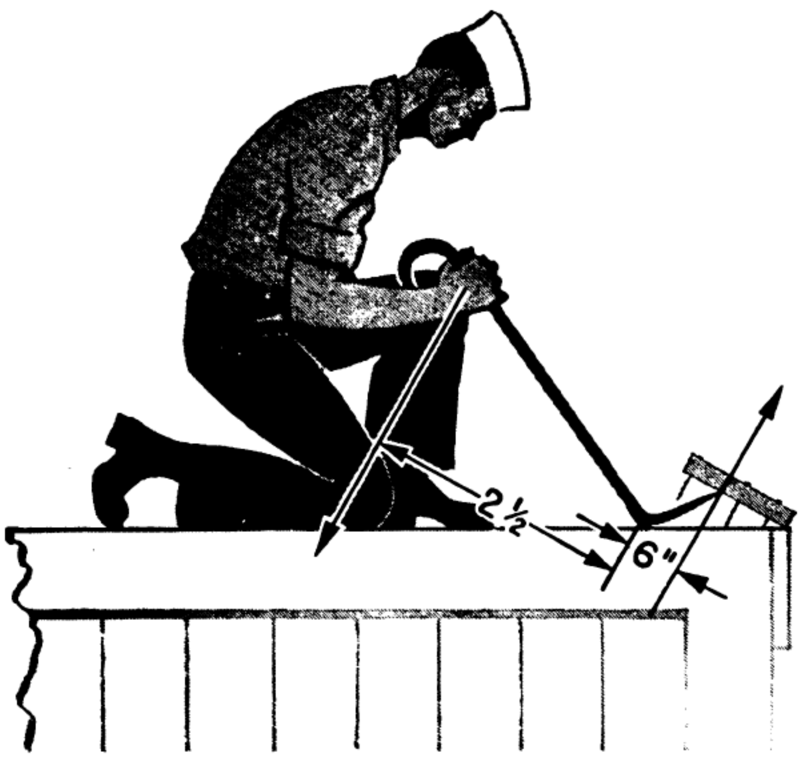



Figure 11.—Using a wrecking bar.

Notice that it has curved lever arms. Can you figure the mechanical advantage of this one? Your answer should be M. A. = 5.

The CRANE in figure 12 is used for handling relatively light loads around a warehouse or a dock. You can see that the crane is rigged as a THIRD-CLASS LEVER. The effort is applied between the fulcrum and the load. This gives a mechanical

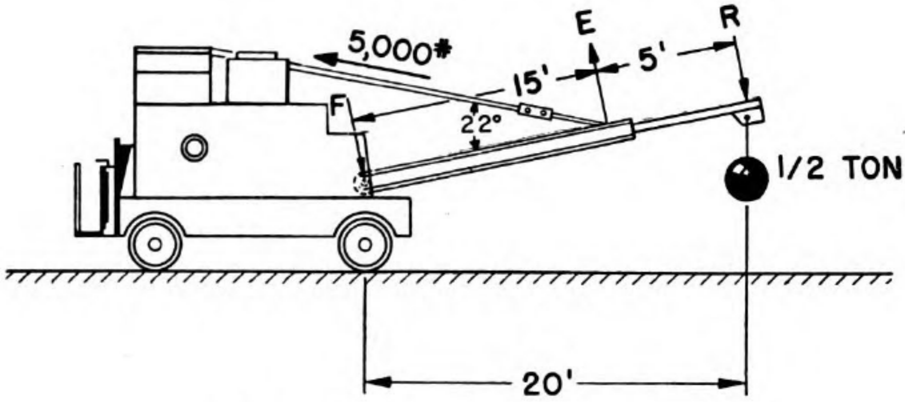
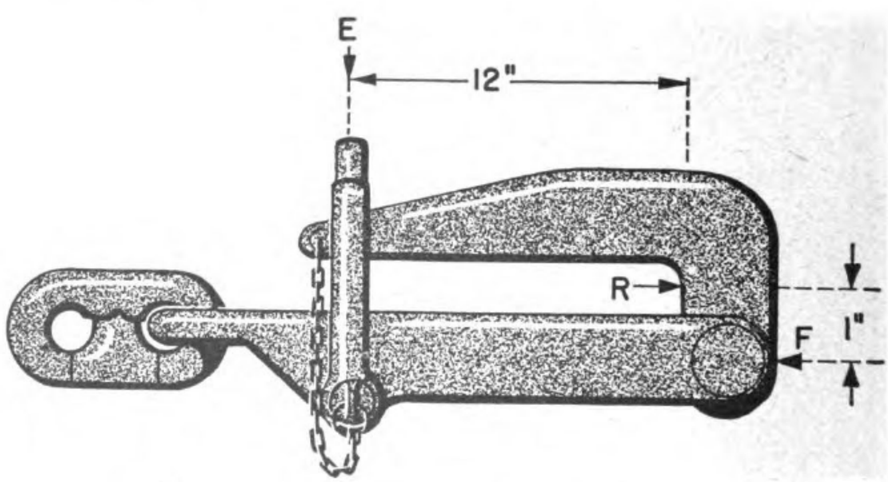


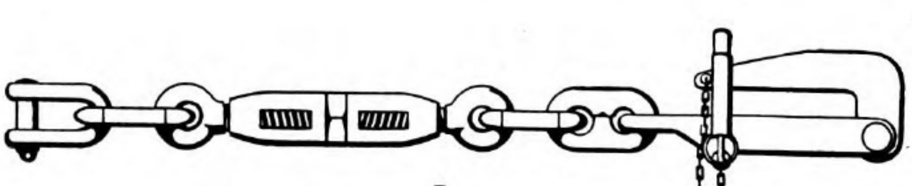

Figure 12.—An electric crane.

advantage of less than one. If she's going to support that ½ ton load, you know that the pull on the lifting cable will have to be considerably greater than 1,000




A

Figure 13a.—A pelican hook.



B

13b.—A chain stopper.

pounds. How much greater? Use the elbow formula on page 13, and figure it out—

$$\frac{L}{l}=\frac{R}{E}$$

Got the answer? Right—$E=1,333$ lb.

Now, because the cable is pulling at an angle of about 22° at E, you can use some trigonometry to find that the pull on the cable will be about 3,560 pounds to lift the ½-ton weight! However, since the loads are generally light, and speed is important, it is a practical and useful machine.

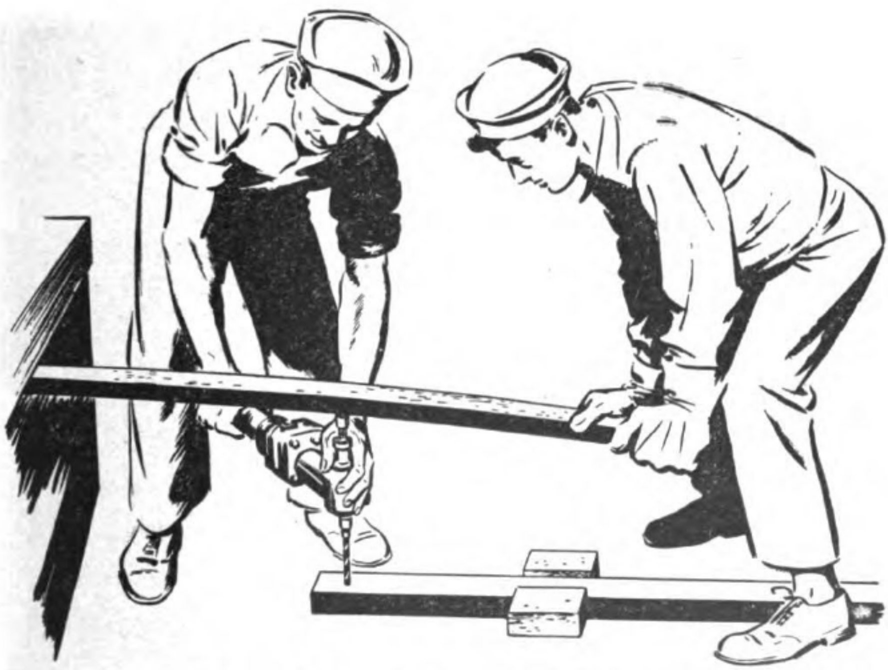


Figure 14.—An improvised drill press.

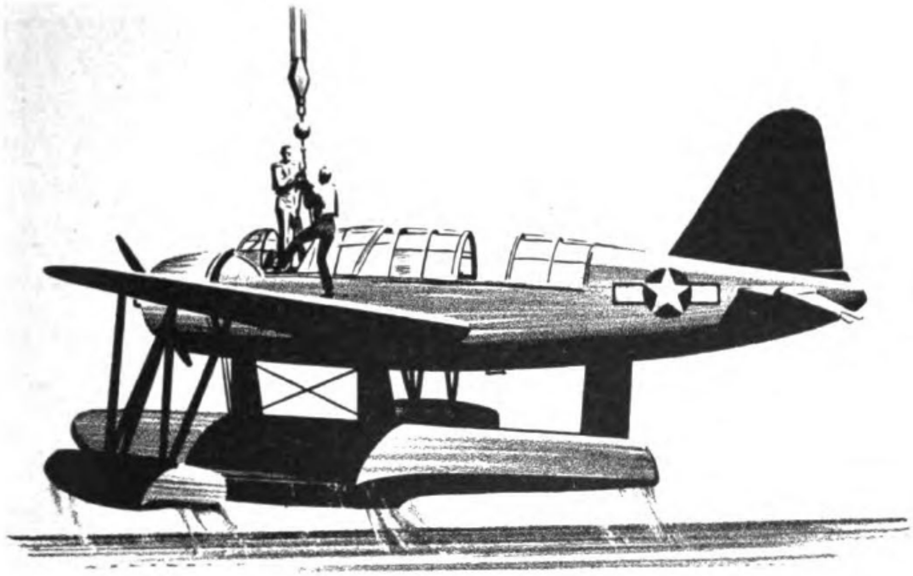
Anchors are usually housed in the hawsepipe and secured by a CHAIN STOPPER. The chain stopper consists of a short length of chain containing a turnbuckle and a PELICAN HOOK. When you secure one end of the stopper to a pad eye in the deck and lock the pelican hook over the anchor chain, the winch is relieved of the strain.

Figure 13a gives you the details of the pelican hook.

Figure 13b shows the chain stopper as a whole. Notice that the load is applied close to the fulcrum. The resistance arm *a* is very short. The bale shackle, which holds the hook secure, exerts its force at a considerable distance *A* from the fulcrum. If the chain rests against the hook one inch from the fulcrum, and the bale shackle is holding the hook closed 12+1=13 inches from the fulcrum, what's the mechanical advantage? It's 13. A strain of only 1,000 pounds on the bale shackle can hold the hook closed when a 6½-ton anchor is dangling over the ship's side. You'll recognize the pelican hook as a SECOND-CLASS LEVER with CURVED ARMS.

Figure 14 shows you a couple of guys who are using their heads to spare their muscles. Rather than exert themselves by bearing down on that DRILL, they pick up a board from a nearby crate and use it as a second-class lever.

If the drill is placed half way along the board, they will get a mechanical advantage of two. How would you increase the mechanical advantage if you were using this rig? Right. You move the drill in closer to the fulcrum. In the Navy, a knowledge of levers and how to apply them pays off.



## CHAPTER 2

# BLOCKS AND TACKLE

## WHAT THEY ARE

BLOCKS—PULLEYS to a landlubber—are simple machines that have many uses aboard ship, as well as shore. Remember how your mouth hung open as you watched movers taking a piano out of a fourth story window? The fat guy on the end of the tackle eased the piano safely to the sidewalk with a mysterious arrangement of blocks and ropes. Or perhaps you've been in the country and watched the farmer use a block-and-tackle to put hay in a barn. Since old Dobbin or the tractor did the hauling, there was no need for a fancy arrangment of ropes and blocks. Incidentally, you'll often hear the rope or tackle called the FALL. Block-and-tackle, or block-and-fall.

In the Navy you'll rig a block-and-tackle to make some of your work easier. Learn the names of the parts of a block. Figure 15 will give you a good start on this. Look at the single block and see some of the ways you can use it. If you lash a single block to a fixed object—an overhead, a yardarm, or a bulkhead—you give yourself the advantage of being able to pull from a convenient direction. For example, in figure 16 you haul UP a flag hoist, but you really pull DOWN. You can do this by having a single sheaved block made fast to the yardarm. This makes it possible for you to stand in a convenient

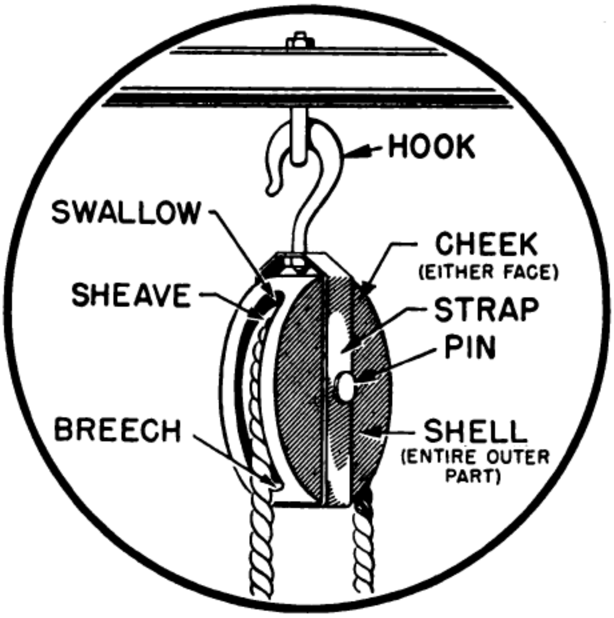



Figure 15.—Look it over.

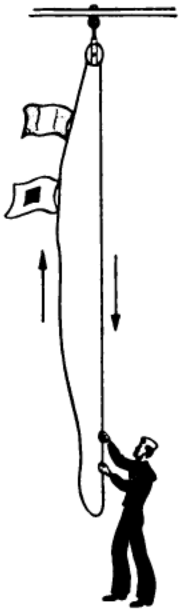


Figure 16.—A flag hoist.

place near the flag bag and do the job. Otherwise you would have to go aloft, dragging the flag hoist behind you.

## MECHANICAL ADVANTAGE

With a single fixed sheave, the force of your down-pull on the FALL must be equal to the weight of the object being hoisted. You can't use this rig to lift a HEAVY LOAD or resistance with a SMALL EFFORT—you can change only the DIRECTION of your pull.

A SINGLE FIXED BLOCK is really a FIRST-CLASS LEVER with EQUAL ARMS. The arms *EF* and *FR* in figure 17 are equal; hence the mechanical advantage is ONE. When you pull down at *A* with a force of one pound, you raise a load of one pound at *B*, a SINGLE FIXED BLOCK does not magnify force nor speed.

You can, however, use a single block-and-fall to MAGNIFY the force you exert. Notice, in figure 18, that the block is NOT FIXED, and that the fall is DOUBLED as it supports the 200-pound cask. When rigged this way, a single block-and-fall is called a RUNNER. Each half of the fall carries one half of

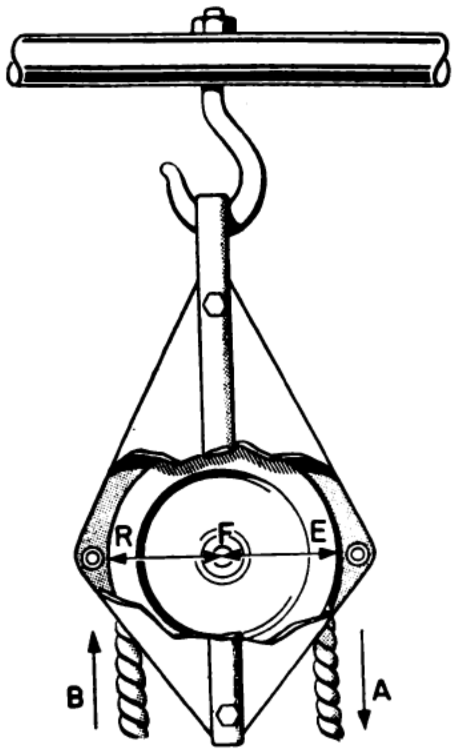


Figure 17.—No advantage.

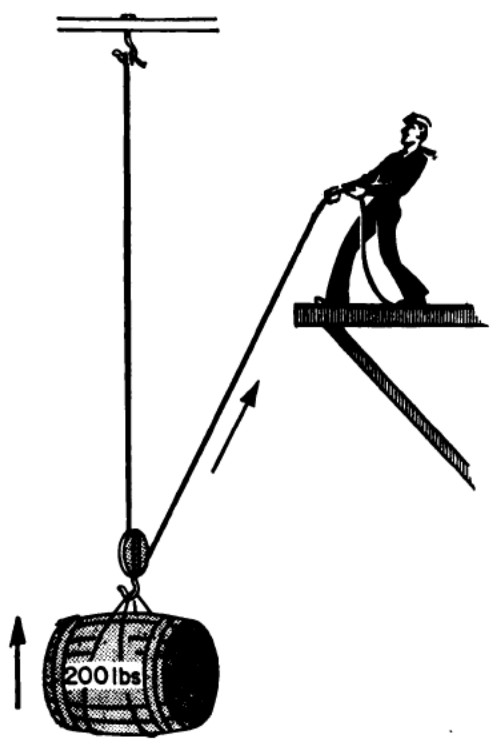


Figure 18.—A runner.

the total load, or 100 POUNDS. Thus, by the use of the runner, the bluejacket is lifting a 200-pound cask with a 100-pound pull. The mechanical advantage is two. Check this by the formula:

$$M.\ A. = \frac{R}{E} = \frac{200}{100},\ or\ 2$$

The single movable block in this set-up is really a SECOND-CLASS LEVER. See figure 19. Your effort *E* acts upward upon the arm $EF$, which is the diameter of the sheave. The resistance $R$ acts downward on the arm $FR$, which is the RADIUS of the sheave. Since the diameter is twice the radius, the mechanical advantage is two.

But, when the effort at $E$ moves up TWO feet, the load at $R$ is raised only ONE foot. That's one thing

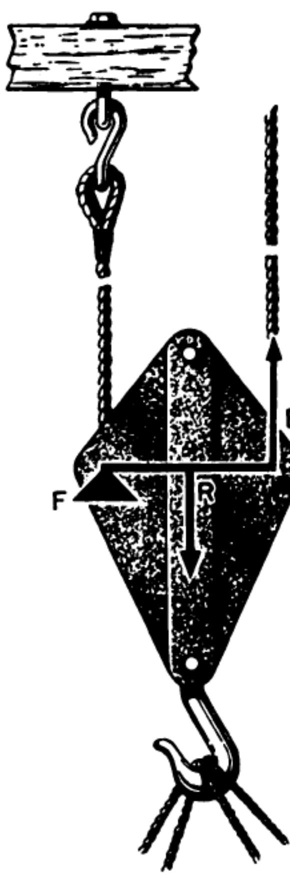



Figure 19.—It's 2 to 1.

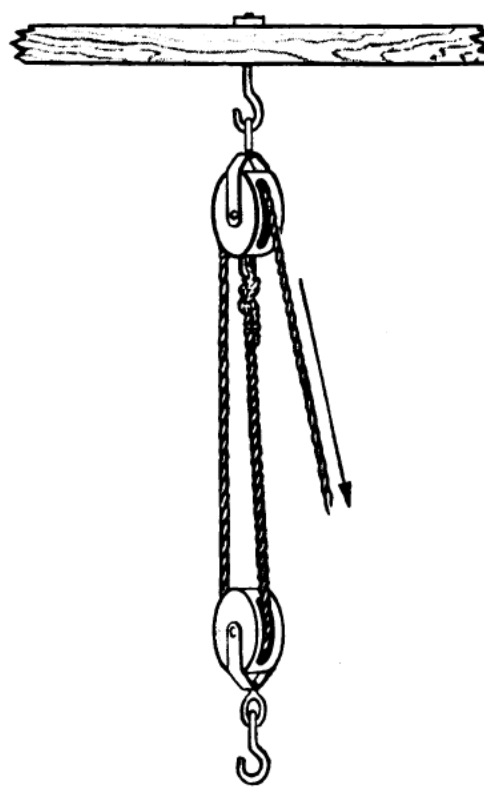


Figure 20.—A gun tackle.

to remember about blocks and falls—if you are actually getting a mechanical advantage from the system, the length of rope that passes through your hands is greater than the distance that the load is raised. However, if you can lift a big load with a small effort, you don't care how much rope you have to pull.

The bluejacket in figure 18 is in an awkward position to pull. If he had another single block handy, he could use it to change the direction of the pull, as in figure 20. This second arrangement is known as a GUN TACKLE PURCHASE. Of course, the fact that the second block is fixed merely changes the direction of pull—and the mechanical advantage of the whole system remains two.

## MORE MECHANICAL ADVANTAGE

You can arrange blocks in a number of ways, depending on the job to be done and the mechanical advantage you want to get. For example, a LUFF TACKLE consists of a double block and a single block, rigged as in figure 21. Notice that the weight is suspended by the three parts of rope which extend from the movable single block. Each part of the rope carries its share of the load. If the crate weighs 600 pounds, then each of the three parts of the rope supports its share—200 pounds. If there's a pull of 200 pounds downward on rope *B*, you will have to pull downward with a force of 200 pounds on *A* to counter-balance the pull on *B*. Neglecting the friction in the block, a pull of 200 pounds is all that is necessary to raise the crate. The mechanical advantage is:

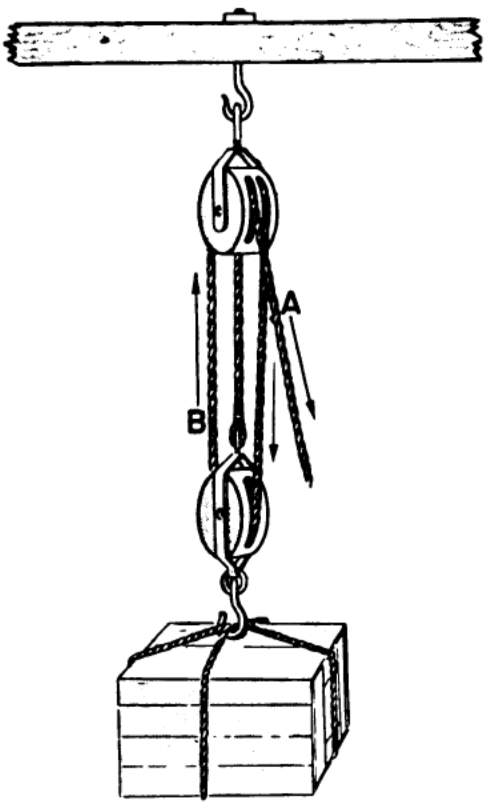


Figure 21.—A luff tackle.

$$M.A.=\frac{R}{E}=\frac{600}{200}=3$$

Here's a good tip. If you count the number of the parts of rope going to and from the movable block, you can figure the mechanical advantage at a glance. This simple rule will help you to quickly approximate

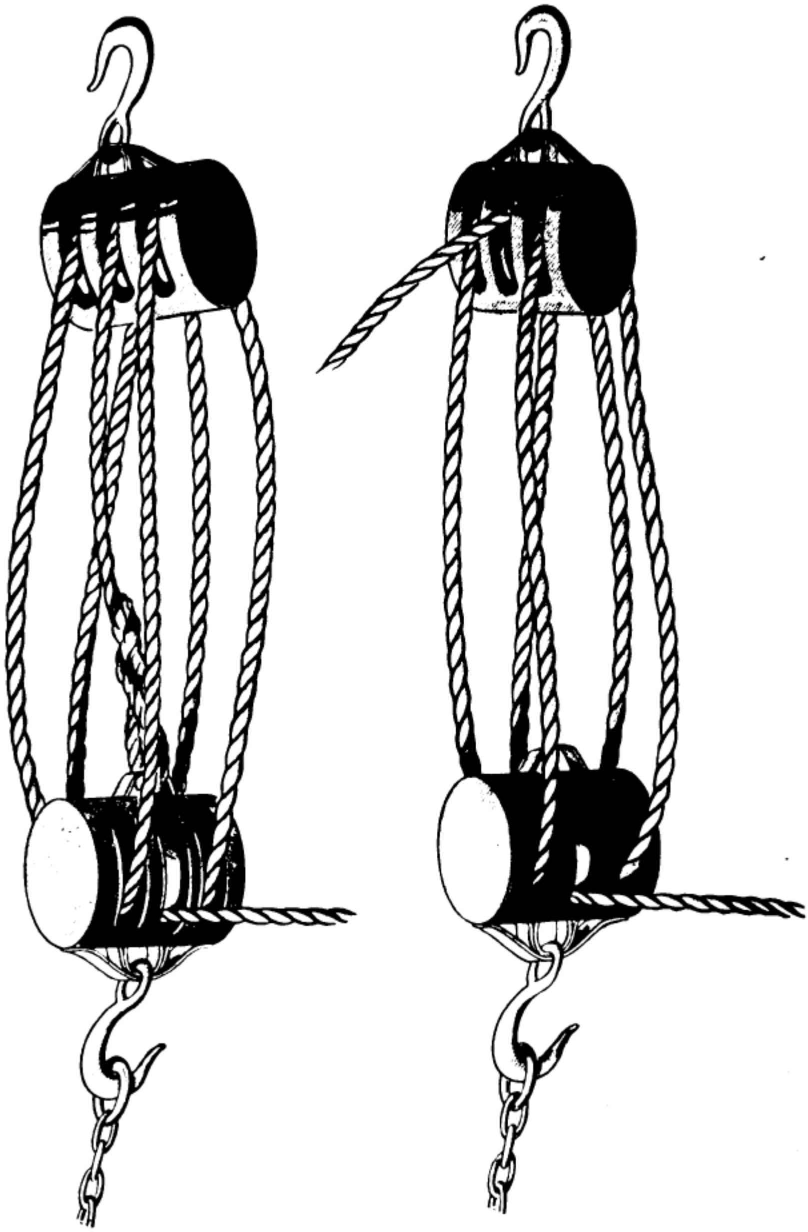


Figure 22.—Some other tackles.

the mechanical advantage of most tackles you see in the Navy.

Many combinations of single, double, and triple sheave blocks are possible. Two of these combinations are shown in figure 22.

If you can secure the dead end of the fall to the movable block, the advantage is INCREASED BY ONE. Notice that this is done in figure 21. That is a good point to remember. Don't forget, either, that the strength of your fall—rope—is a limiting factor in any tackle. Be sure your fall will carry the load. There is no point in rigging a six-fold purchase which carries a 5-ton load with two triple blocks on a 3-inch manila rope attached to a winch. The winch could take it, but the rope couldn't.

Now for a review of the points you have learned about BLOCKS, and then to some practical applications aboard ship—

> With a single FIXED block the only advantage is the change of direction of the pull. The mechanical advantage is still ONE.
>
> A single MOVABLE block gives a mechanical advantage of TWO.
>
> Many combinations of single, double, and triple blocks can be rigged to give greater advantages.
>
> A general rule of thumb is that the number of the parts of the fall going to and from the movable block tells you the approximate mechanical advantage of that tackle.
>
> If you fix the dead end of the fall to the movable block you INCREASE the mechanical advantage by one.

## APPLICATIONS AFLOAT AND ASHORE

Blocks and tackle are used for a great number of lifting and moving jobs afloat and ashore. The five or six basic combinations are used over and over again in many situations. Cargo is loaded aboard, depth charges are placed in their racks, life boats are lowered over the side by the use of this machine. Heavy machinery, guns, and gun mounts are swung into position with the aid of blocks and tackle. In a thousand situations, bluejackets find this machine useful and efficient.

YARD AND STAY TACKLES are used on shipboard when you want to pick up a load from the hold and swing it onto the deck, or to shift any load a short distance. Figure 23 shows you how the load is first picked up by the YARD TACKLE. The STAY

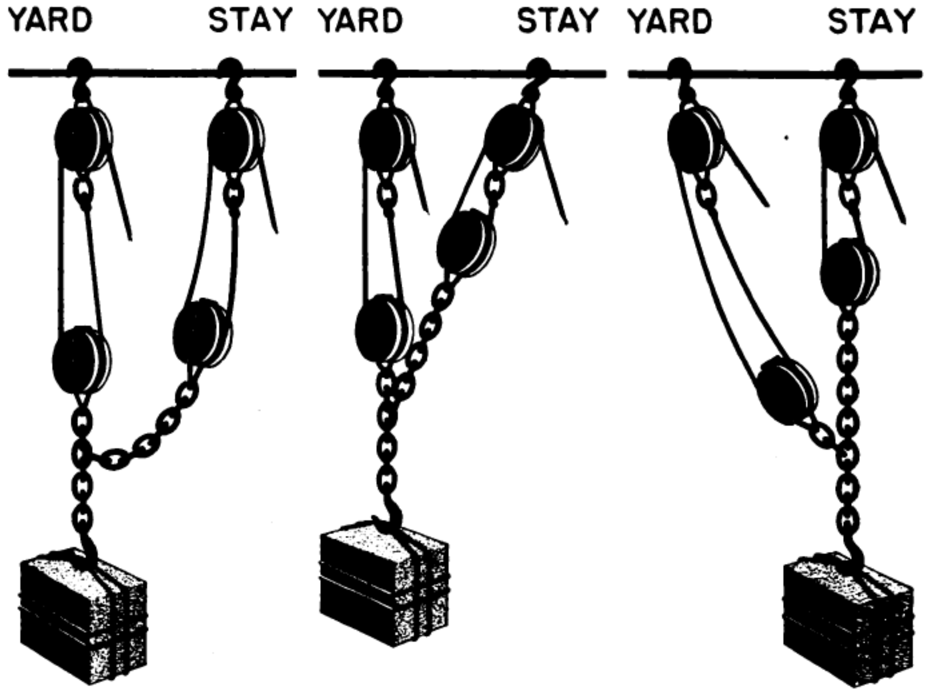



Figure 23.—A yard and stay tackle.

TACKLE is left slack. After the load is raised to the height necessary to clear obstructions, you take up on the stay tackle, and ease off on the yard fall. A glance at the rig tells you that the mechanical advantage of each of these tackles is only two. You may think that it isn't worth the trouble to rig a yard and stay tackle with that small advantage just to move a *400*-pound crate along the deck. However, a few minutes spent in rigging may save many unpleasant hours with a sprained back.

If you want a HIGH mechanical advantage, a LUFF UPON LUFF is a good rig for you. You can raise HEAVY loads with this baby. Figure 24 shows you how it is rigged. If you apply the rule by which you count the parts of the fall going to and from the movable blocks, you find that block *A* gives a mechanical advantage of 3 to 1. Block *B* has four parts of fall running to and from it, a mechanical advantage of 4 to 1. The mechanical advantage of those obtained from *A* is MULTIPLIED four times in *B*. The over-all mechanical advantage of a LUFF UPON LUFF is the PRODUCT of the two mechanical advantages—or 12.

DON'T make the mistake of ADDING mechanical advantages. Always MULTIPLY them.

You can easily figure out the M. A. for the apparatus shown in figure 24. Suppose the load weighs 1,200 pounds. Since it is supported by the

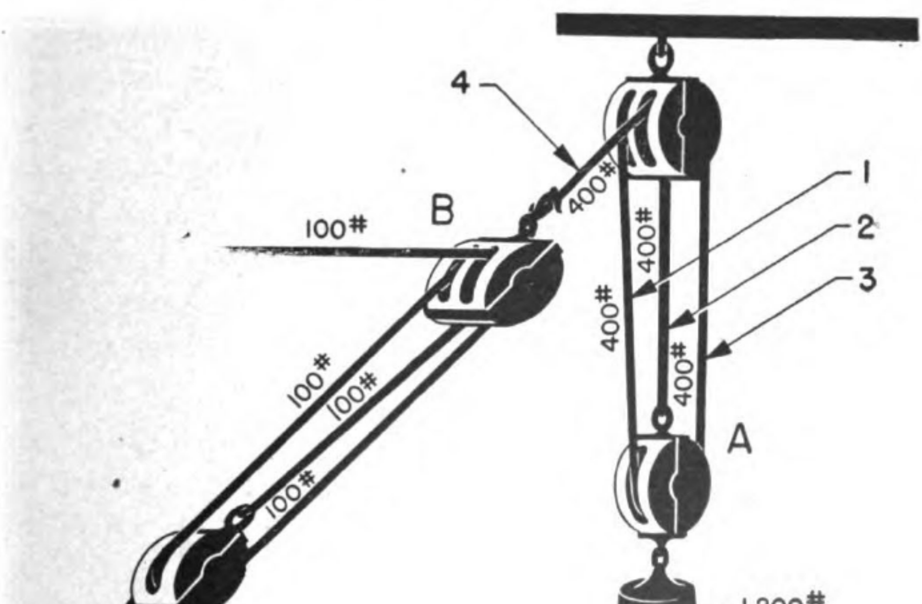



Figure 24.—Luff upon luff.

parts 1, 2, and 3 of the fall running to and from block *A*, each part must be supporting ONE THIRD of the load, or 400 pounds. If part 3 has a pull of 400 pounds on it, part 4 which is made fast to block *B*, also has a 400-pound pull on it. There are four parts of the second fall going to and from block *B*, and each of these takes an equal part of the 400-pound pull.

Therefore, the hauling part requires a pull of only $\frac{1}{4} \times 400$, or 100 pounds. So, here you have a 100-pound pull raising a 1,200-pound load. That's a mechanical advantage of 12.

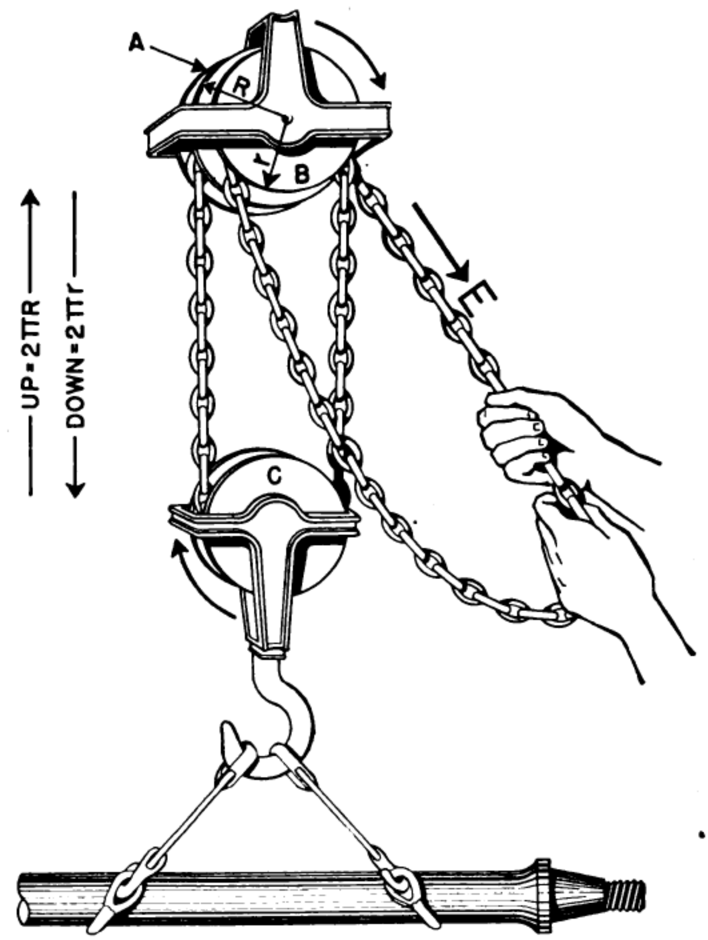



Figure 25.—A chain hoist.

In shops ashore and aboard ship you are almost certain to run into a CHAIN HOIST, or DIFFERENTIAL PULLEY. Ordinarily, these hoists are suspended from overhead trolleys, and are used to lift heavy objects and move them from one part of the shop to another.

To help you to understand the operation of a chain hoist, look at the one in figure 25. Assume that you grasp the chain at *E* and pull until the large wheel *A* has turned around once. Then the distance through which your effort has moved is equal to the circumference of that wheel, or $2\pi R$. How much will the lower wheel $C$ and its load be raised? Since wheel $C$ is a SINGLE MOVABLE BLOCK, its center will be raised only one-half the distance that the chain $E$ was pulled, or a distance $\pi R$. However, the smaller wheel $B$, which is rigidly fixed to $A$, makes one revolution at the same time as $A$ does so $B$ will feed some chain down to $C$. The length of the chain fed down will be equal to the circumference of $B$, or $2\pi r$. Again, since $C$ is single movable block, the downward movement of its center will be equal to only one-half the length of the chain fed to it, or $\pi r$.

Of course, $C$ does not first move up a distance $\pi R$ and then move down a distance $\pi r$. Actually, its steady movement UPWARD is equal to the DIFFERENCE between the two, or $(\pi R - \pi r)$. Don't worry about the size of the movable pulley, $C$. It doesn't enter into these calculations. Usually its diameter is between that of $A$ and that of $B$.

The mechanical advantage equals the distance through which the effort $E$ is moved, divided by the distance that the load is moved. This is called the VELOCITY RATIO, OF THEORETICAL MECHANICAL ADVANTAGE. It is theoretical because the frictional resistance to the movement of mechanical parts is left out. In practical uses, all moving parts have frictional resistance.

The equation for theoretical mechanical advantage may be written—

$$\text{Theoretical mechanical advantage} = \frac{\text{Distance effort moves}}{\text{Distance resistance moves}}$$

and in this case,

$$T.\ M.\ A. = \frac{2\pi R}{\pi R - \pi r} = \frac{2R}{(R-r)}$$

If $A$ is a large wheel, and $B$ is a little smaller, the value of $2R$ becomes large, and $(R-r)$ becomes small. Then you have a large number for $\frac{2R}{(R-r)}$ which is the theoretical mechanical advantage.

You can lift heavy loads with chain hoists. To give you an idea of the mechanical advantage of a chain hoist, suppose the large wheel has a radius $R$ of 6 inches and the smaller wheel a radius $r$ of 5¾ inches. What theoretical mechanical advantage would you get? Use the formula—

$$T.\ M.\ A. = \frac{2R}{R-r}$$

Then substitute the numbers in their proper places, and solve—

$$T.\ M.\ A. = \frac{2 \times 6}{6 - 5\frac{3}{4}} = \frac{12}{\frac{1}{4}} = 48$$

Since the friction in this type of machine is considerable, the ACTUAL mechanical advantage is not as high as the THEORETICAL mechanical advantage would lead you to believe. For example, that theoretical mechanical advantage of 48 tells you that with a one-pound pull you should be able to lift a 48-pound load. However, actually your one-pound pull might only lift a 20-pound load. The rest of your effort would be used in overcoming the friction.

## CHAPTER 3

# THE WHEEL AND AXLE

### WHEELS WITHIN WHEELS

Have you ever tried to open a door when the knob was missing? If you have, you know that trying to twist that small four-sided shaft with your fingers is tough work. That gives you some appreciation of the advantage you get by using a knob. The door knob is a homely example of a SIMPLE MACHINE called a WHEEL AND AXLE.

The steering wheel on an automobile, the handle of an ice cream freezer, a brace and bit—these are familiar examples of this type of simple machine. As you know from your experience with these devices, the wheel and axle is commonly used to multiply the force you exert. If a screwdriver won't do a job because you can't turn it, you stick a screwdriver bit in the chuck of a brace and the screw probably goes in with little difficulty.

There's one thing you'll want to get straight right at the beginning. The wheel-and-axle machine consists of a WHEEL OR CRANK RIGIDLY ATTACHED TO THE AXLE, which turns with the wheel. Thus, the front wheel of an automobile is NOT a wheel-and-axle machine because the axle does not turn with the wheel.

## FIGURE IT OUT

How does the wheel-and-axle arrangement help to magnify the force you exert? Suppose you use a screwdriver bit in a brace to drive a stubborn screw. Look at figure 26*A*. Your effort is applied

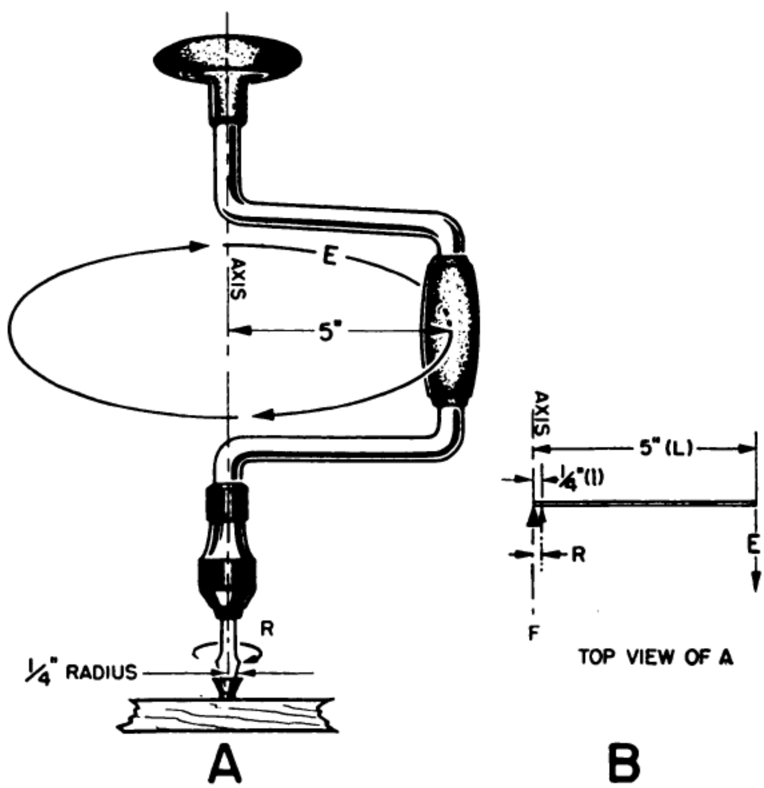



Figure 26.—It magnifies your effort.

on the handle which moves in a circular path, the radius of which is 5 inches. If you apply a 10-pound force on the handle, how big a force will be exerted against the resistance at the screw? Assume the radius of the screwdriver blade is ¼ inch. You are really using the brace as a second-class lever—see figure 26*B*. The size of the resistance which can be overcome can be found from the formula—

$$\frac{L}{l}=\frac{R}{E}$$

In which—

$L$ = radius of the circle through which the handle turns,

$l$ = one-half the width of the edge of the screwdriver blade,

$R$ = force of the resistance offered by the screw,

$E$ = force of effort applied on the handle.

Substituting in the formula; and solving:

$$\frac{5}{\frac{1}{4}}=\frac{R}{10}$$

$$R=\frac{5\times10}{\frac{1}{4}}$$

$$=5\times10\times4$$

$$=200 \text{ lb.}$$

This means that the screwdriver blade will tend to turn the screw with a force of 200 pounds. The relationship between the radii or the diameters, or

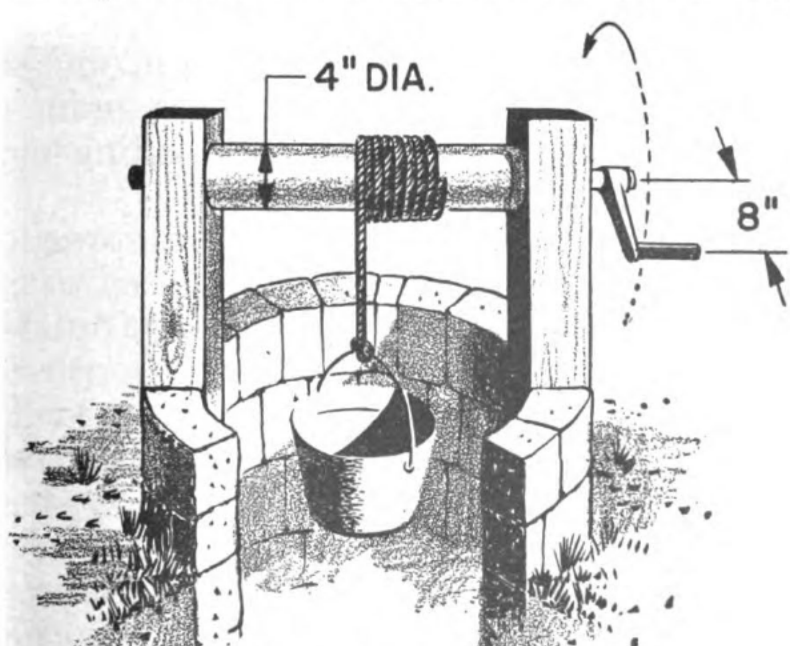



Figure 27.—The Old Oaken Bucket.

the circumferences of the wheel and axle tells you how great a mechanical advantage you can get.

Take another situation. The old oaken bucket, figure 27, was raised by a wheel-and-axle arrangement. If the distance from the center of the axle to the handle is 8 inches, and the radius of the drum around which the rope is wound is 2 inches, then you have a theoretical mechanical advantage of 4. That's why they used these rigs.

## ON THE DOUBLE

In a number of situations you can use the wheel-and-axle to SPEED UP MOTION. The rear-wheel sprocket of a bike, along with the rear wheel itself, is an example. When you are pedaling, the sprocket is fixed to the wheel, so the combination is a true wheel-and-axle machine. Assume that the sprocket has a circumference of 8 inches, and the wheel circumference is 80 inches. If you turn the sprocket at a rate of one revolution per second, each sprocket tooth moves at a SPEED of 8 inches per second. Since the wheel makes one revolution for each revolution made by the sprocket, any point on the tire must move through a distance of 80 inches in one second. So, for every eight-inch movement of a point on the sprocket, you have moved a corresponding point on the wheel through 80 inches.

Since a complete revolution of the sprocket and wheel requires only one second, the speed of a point on the circumference of the wheel is 80 inches per second, or ten times the speed of a tooth on the sprocket.

(NOTE: Both sprocket and wheel make the same number of revolutions per second so the SPEED OF TURNING for the two is the same.)

Here is an idea which you will find useful in understanding the wheel and axle, as well as other machines. You probably have noticed that the force you apply to a lever tends to turn or ROTATE it about the fulcrum? You also know that a heave on a fall tends to ROTATE the sheave of the block and that turning the steering wheel of a car tends to ROTATE the steering column. Whenever you use a lever, or a wheel and axle, your effort on the lever arm or the rim of the wheel tends to cause a ROTATION about the fulcrum or the axle in one direction or another. If the rotation occurs in the SAME direction as the hands of a clock, that direction is called CLOCKWISE. If the rotation occurs in the OPPOSITE direction from that of the hands of a clock, the direction of rotation is called COUNTERCLOCKWISE. A glance at figure 28 will make clear the meaning of these terms.

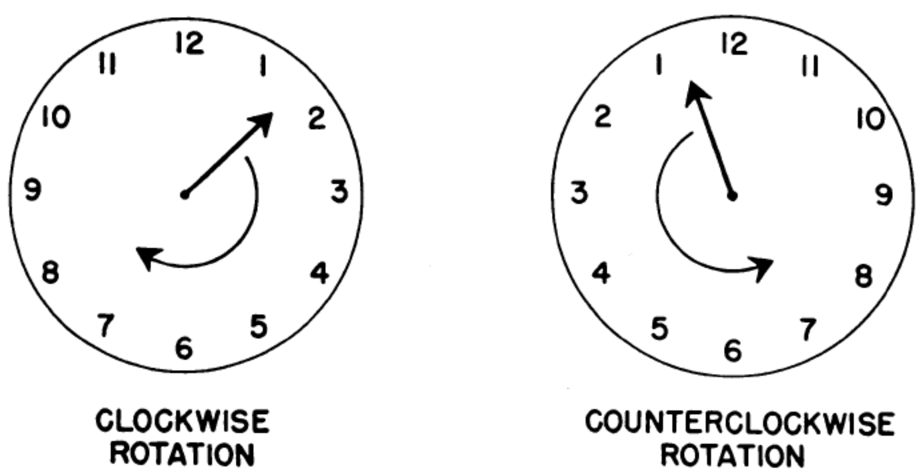



Figure 28.—Directions of rotation.

You have already seen that the RESULT of a force acting on the handle of the carpenter's brace depends not only on the amount of that force but also on the distance from the handle to the center of rotation. From here on you'll know this RESULT as a MOMENT OF FORCE, or a TORQUE (pronounced *tork*). MOMENT OF FORCE and TORQUE have the same meaning.

Look at the effect of counterclockwise movement of the capstan bar in figure 29. Here the amount of the effort is designated $E_1$ and the distance from the point where this force is applied to the center of the axle is $L_1$. Then $E_1 \times L_1$ is the MOMENT OF FORCE. You'll notice that this term includes BOTH the amount of the effort and the distance from the point of application of effort to the center of the axle. Ordinarily, the distance is measured in FEET and the applied force is measured in POUNDS.

Therefore, MOMENTS OF FORCE are generally measured in FOOT-POUNDS—abbreviated ft.-lb. A MOMENT OF FORCE is frequently called a MOMENT.

By using a longer capstan bar, the bluejacket in figure 29 can increase the EFFECTIVENESS of his PUSH

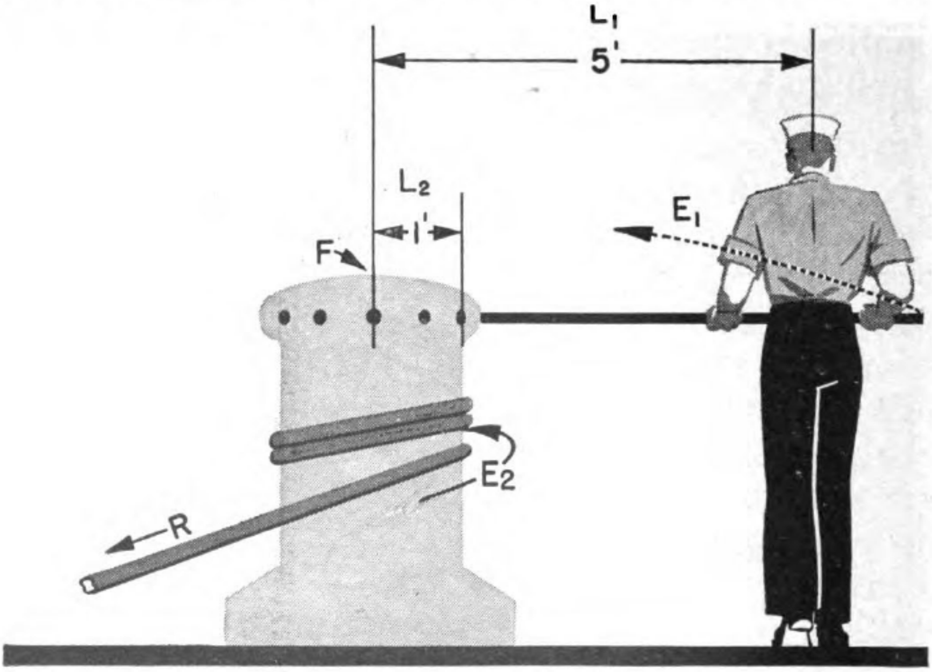



Figure 29.—Using a capstan.

without making a bigger effort. But if he applied his effort closer to the head of the capstan and used the SAME FORCE, the MOMENT OF FORCE would be LESS.

## MOMENTS BALANCE ONE ANOTHER

You know that the bluejacket in figure 29 would land flat on his face if the anchor hawser snapped. But just as long as nothing breaks, he must continue to push on the capstan bar. He is working against a

CLOCKWISE MOMENT OF FORCE, which is equal in magnitude but opposite in direction to his counterclockwise moment of force. The resisting moment, like the effort moment, depends on two factors. In the case of the resisting moment, these factors are the force $R_2$ with which the anchor pulls on the hawswer, and the distance $L_2$ from the center of the capstan to its rim. The existence of this resisting force would be evident if the bluejacket let go of the capstan bar. The weight of the anchor pulling on the capstan would cause the whole works to spin rapidly in a clockwise direction—and good-bye anchor! The principle involved here is that WHENEVER THE COUNTERCLOCKWISE AND THE CLOCKWISE MOMENTS OF FORCE ARE IN BALANCE, THE MACHINE EITHER MOVES AT A STEADY SPEED OR REMAINS AT REST.

This idea of the BALANCE of moments of force can be summed up by the expression—

**CLOCKWISE MOMENTS=COUNTERCLOCKWISE MOMENTS**

And, since a moment of force is the product of the AMOUNT of the force times the DISTANCE the force acts from the center of rotation, this expression of equality may be written—

$$E_1 \times L_1 = E_2 \times L_2$$

In which—

$E_1$ = force of effort,

$L_1$ = distance from fulcrum or axle to point where force is applied,

$E_2$ = force of resistance,

$L_2$ = distance from fulcrum or center of axle to the point where resistance is applied.

*EXAMPLE 1*

Put this formula to work on a capstan problem. A single capstan bar is gripped 5 feet from the center of a capstan head with a radius of one foot. A ½-ton anchor is to be lifted. How big a push does the sailor have to exert?

First, write down the formula—

$$E_1 \times L_1 = E_2 \times L_2$$

Here $L_1 = 5$; $E_2 = 1{,}000$ pounds; and $L_2 = 1$.

Substitute these values in the formula, and it becomes:

$$E_1 \times 5 = 1{,}000 \times 1$$

and—

$$E_1 = \frac{1{,}000}{5} = 200 \text{ pounds}$$

*Example 2*

Consider now the sad case of Slim and Sam, as illustrated in Figure 30. Slim has suggested that

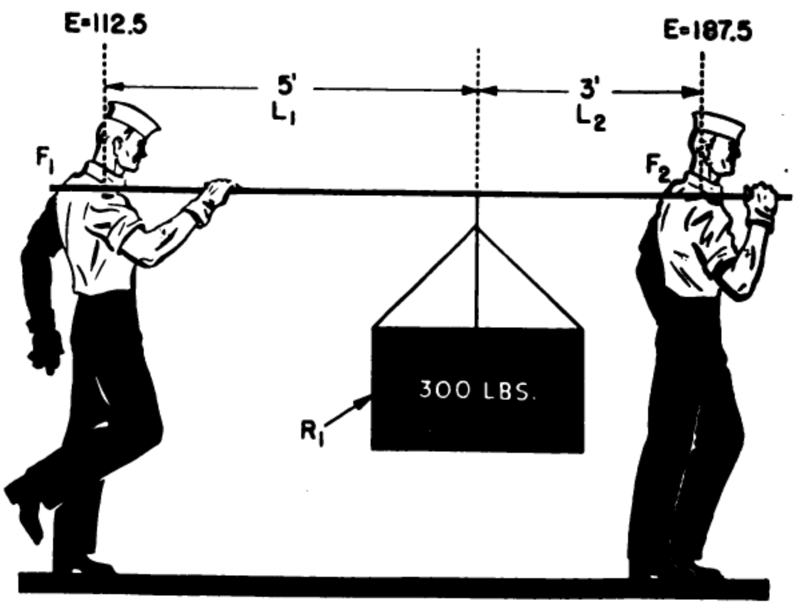



Figure 30.—A practical application.

they carry the 300-pound crate slung on a handy 10-foot pole. He was smart enough to slide the load up 3 feet from Sam's shoulder.

Here's how they made out. Use Slim's shoulder as a fulcrum $F_1$. Look at the CLOCKWISE MOMENT caused by the 300-pound load. That load is five feet away from Slim's shoulder. If $R_1$ is the load, and $L_1$ the distance from Slim's shoulder to the load, the CLOCKWISE MOMENT $M_A$ is—

$$M_A = R_1 \times L_1 = 300 \times 5 = 1{,}500 \text{ ft.-lb.}$$

With Slim's shoulder still acting as the fulcrum, the resistance of Sam's effort causes a COUNTER-CLOCKWISE MOMENT $M_B$ acting against the load moment. This counterclockwise moment is equal to Sam's effort $E_2$ times the distance $L_3$ from his shoulder to the fulcrum $F_1$ at Slim's shoulder. Since $L_2 = 8$ ft., the formula is—

$$M_B = E_2 \times L_3 = E_2 \times 8 = 8E_2$$

But there is no rotation, so the clockwise moment and the counterclockwise moment are equal. $M_A = M_B$. Hence—

$$1{,}500 = 8E_2$$

$$E_2 = \frac{1{,}500}{8} = 187.5 \text{ pounds.}$$

So poor Sam is carrying 187.5 pounds of the 300-pound load.

What is Slim carrying? The difference between 300 and 187.5 = 112.5 pounds, of course! But you can check your answer by this procedure—

This time, use Sam's shoulder as the fulcrum $F_2$. The COUNTERCLOCKWISE MOMENT $M_c$ is equal to the 300-pound load $R_1$ times the distance $L_2$—3 feet—from Sam's shoulder, or $M_c$ $300 \times 3 = 900$ foot-pounds. The CLOCKWISE MOMENT $M_D$ is the result of Slim's lift $E_1$ acting at a distance $L_3$ from the fulcrum. $L_3 = 8$ feet. Again, since counterclockwise moment equals clockwise moment, you have—

$$900 = E_1 \times 8$$

and $$E_1 = \frac{900}{8} = 112.5 \text{ pounds}$$

Slim, the smart sailor, has to lift only 112.5 pounds. There's a blue jacket who really puts his knowledge to work.

## THE COUPLE

Take a look at figure 31. It's another capstan-turning situation. To increase effective effort, a second capstan bar is placed opposite the first and another bluejacket can apply a force on the second bar. The two sailors in figure 31 will apparently be

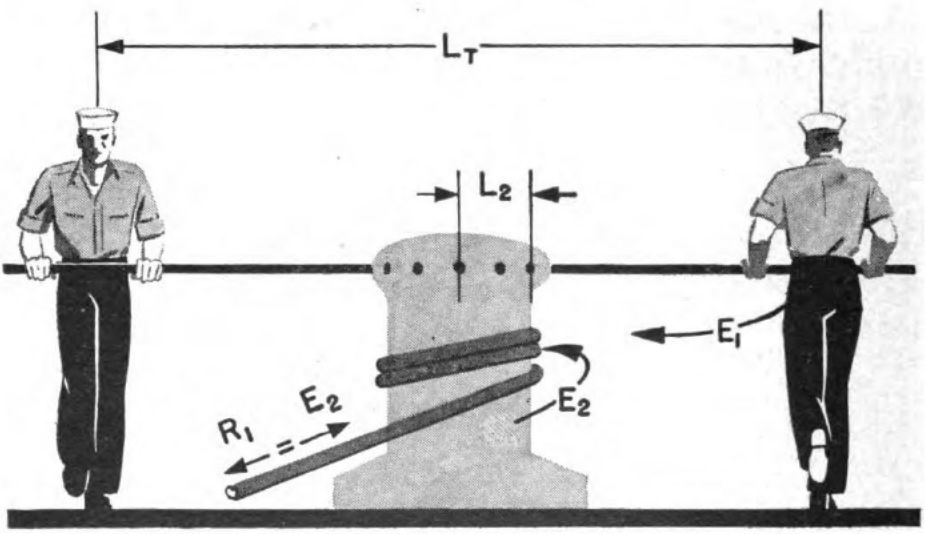



Figure 31.—A couple.

pushing in opposite directions. But, since they are on opposite sides of the axle, they are actually causing ROTATION in the SAME DIRECTION. And, if the two sailors are pushing with equal forces, the moment of force is twice as great as though only one sailor was pushing. This arrangement is known technically as a COUPLE.

You will see that the COUPLE is a special example of the WHEEL AND AXLE. The moment of force is equal to the product of the total distance $L_T$ between the two points of effort and the force $E_1$ applied by ONE sailor. The equation for the couple may be written

$$E_1 \times L_T = E_2 \times L_2$$

## IN REVIEW

Here is a quick review of the WHEEL AND AXLE—things you should have straight in your mind—

A WHEEL-AND-AXLE MACHINE has the WHEEL FIXED RIGIDLY TO THE AXLE. The wheel and the axle turn together.

The wheel and axle may be used either to MAGNIFY your effort or to SPEED IT UP.

The EFFECT of a force tending to rotate an object around an axis or fulcrum is called a MOMENT OF FORCE, or simply a MOMENT.

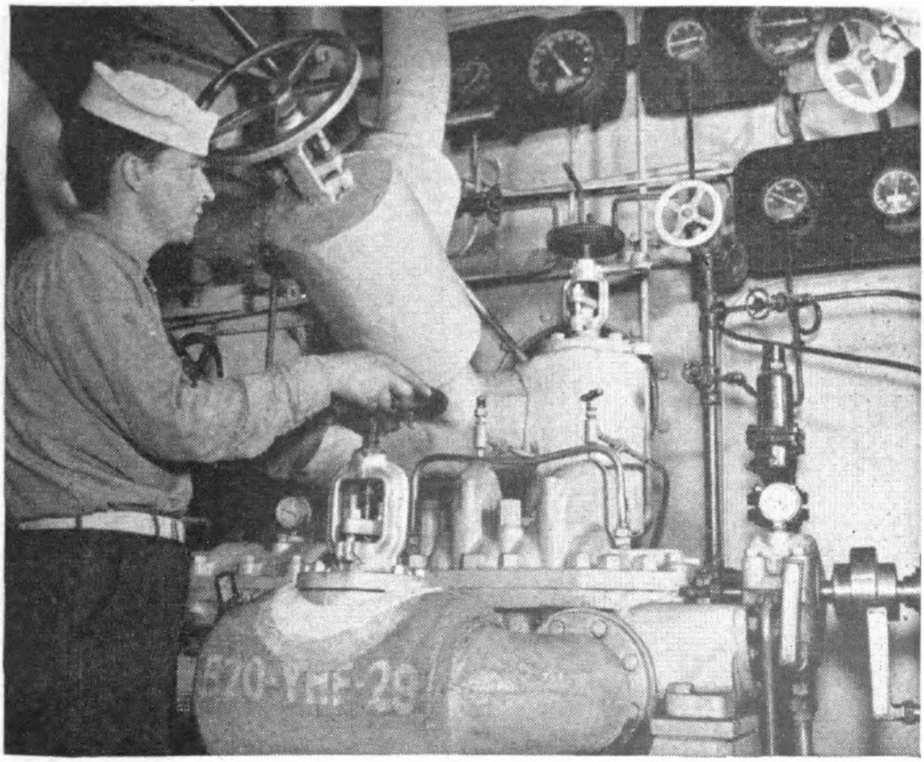



Figure 32.—Valves.

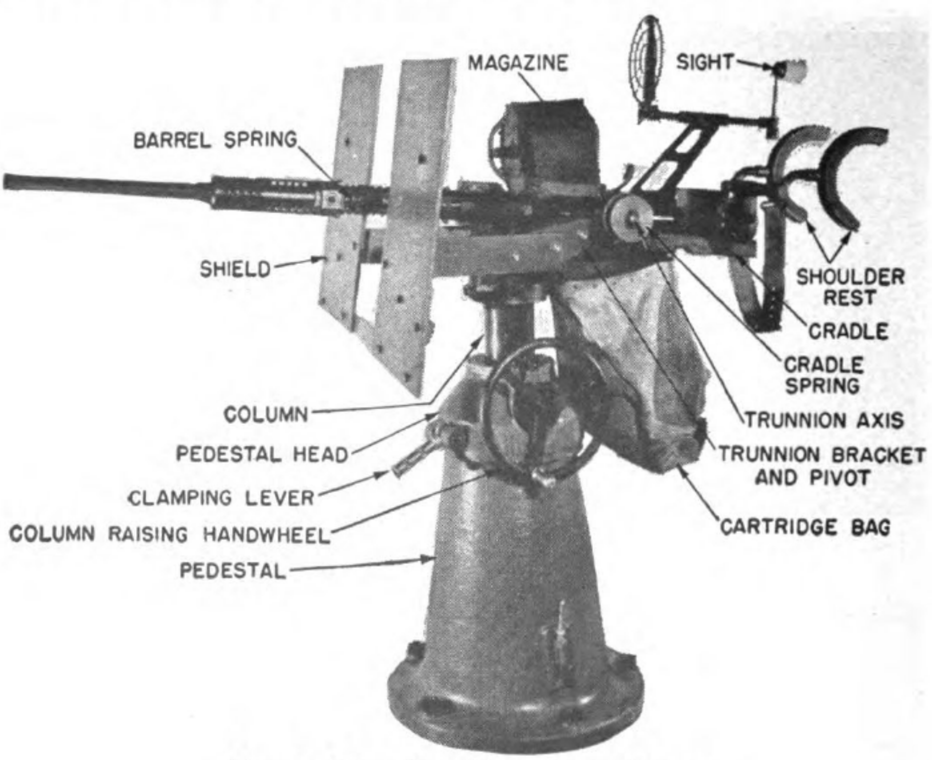
When an object is at REST or is MOVING STEADILY, the clockwise moments are just EQUAL AND OPPOSITE TO the counterclockwise moments.

MOMENTS OF FORCE depend upon TWO factors—the AMOUNT OF THE FORCE, and the DISTANCE from the fulcrum or axis to the point where the force is applied.

When two equal forces are applied at equal distances on opposite sides of a fulcrum, and move in opposite directions so that they both tend to cause rotation about the fulcrum, you have a COUPLE.

## APPLICATIONS AFLOAT AND ASHORE

A trip to the engine room makes you realize how important the WHEEL AND AXLE is on the modern ship. Everywhere you look you see wheels of all sizes and shapes. Most of them are used to open and close valves quickly. One common type of valve is shown in figure 32. Turning the wheel causes the threaded stem to rise and open the valve. Since the valve must close water-tight, air-tight, or steam-tight, all the parts must fit snugly. To move the stem on most valves without the aid of the wheel




**Figures 33.—You'll see lots of these.**

would be impossible. The wheel gives you the necessary mechanical advantage.

You may have watched the crew of a 20-mm. gun in action. The gunner is practically hanging in his sling during the high-elevation shots, and standing upright for the flat ones. The trunnion operator has

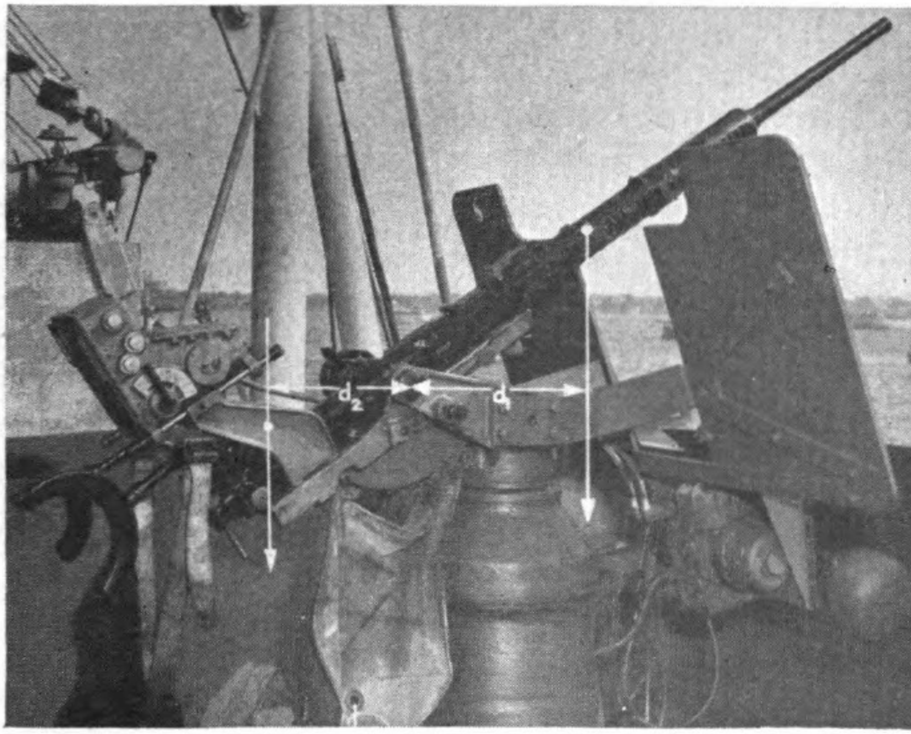



**Figure 34.—Balance is important.**

the important job of keeping the gun at the proper height so that the gunner's legs are just slightly bent at all times. A column in the gun mount can be raised or lowered rapidly to bring the gun to the proper height. Its operation must be smooth and fast so that the gunner can track an attacking airplane. Figure 33 shows you the mount and column-raising handwheel. The handwheel turns the gear system which screws the column up or down. This wheel-and-axle arrangement gives rapid and smooth adjustment of the height of the column.

Here's where a knowledge of MOMENTS OF FORCE comes in handy. If you were the gunner on a 20-mm. gun, you'd want the gun to be well-balanced. You wouldn't want to be always pushing up against the gun or yanking down on her while you followed the target. For that reason, the gun is designed so that it balances at the trunnions. The center of weight of the barrel is located at the point shown in figure 34. The clockwise moment of force tending to depress the muzzle depends on the weight of the barrel acting at the distance $d_1$ forward of the trunnions. To COUNTERBALANCE this moment, the breech end of the gun and the Mark 14 sight are placed so that their weight acts DOWNWARD through the point shown in the illustrations. Notice that this weight, acting at the distance $d_2$ aft of the trunnions, sets up a COUNTERCLOCKWISE moment which tends to RAISE the muzzle. The designer located the gun trunnions so that these two moments would be EQUAL and OPPOSITE. Hence, the gun can be elevated or depressed with fingertip pressure.

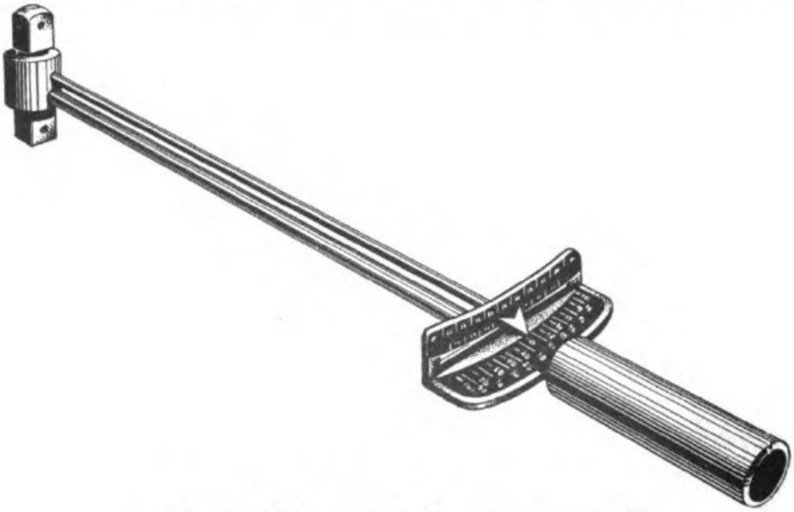


Figure 35.—A simple torque wrench.

You've handled enough WRENCHES to know that the longer the handle, the tighter you can turn a nut. Actually, a wrench is a WHEEL-AND-AXLE MACHINE. You can consider the handle as one spoke of a wheel, and the place where you take hold of the handle as a point on the rim. The nut which is held in the jaws of the wrench can be compared to the axle.

You know that you can turn a nut too tight—and strip the threads. This is especially true when you are taking up on bearings. In order to make the proper adjustment, you use a TORQUE WRENCH. There are several types. Figure 35 shows you one that is very simple. When you pull on the handle,

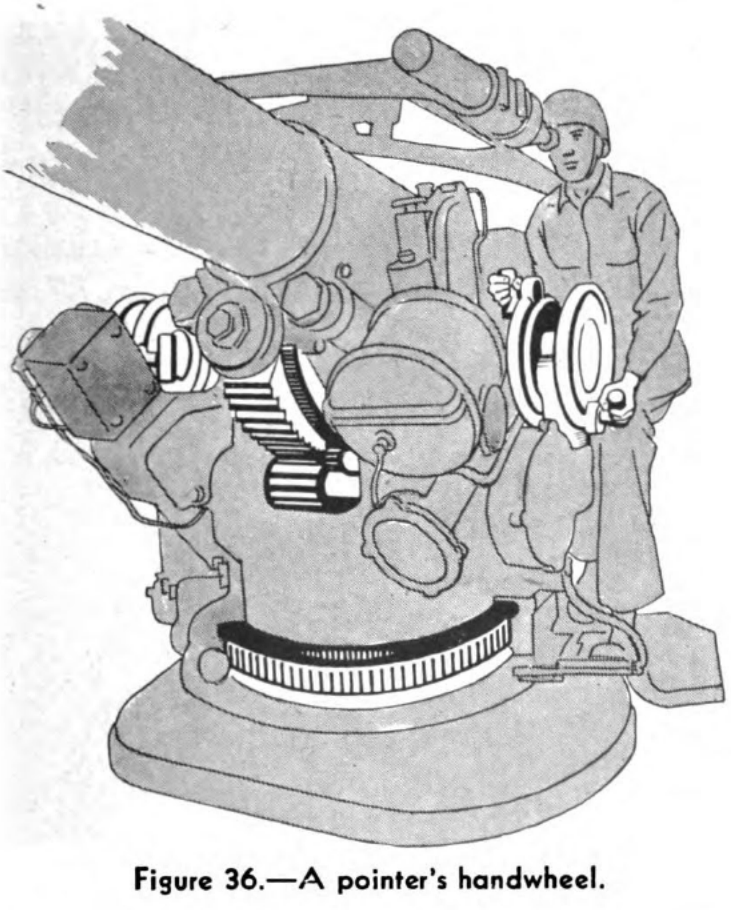


Figure 36.—A pointer's handwheel.

its shaft bends. The rod on which the pointer is fixed does not bend—so the pointer indicates on the scale the torque, or moment of force, that you are exerting. The scale is generally stated in pounds, although it is really measuring FOOT-POUNDS OF TORQUE. If the nut is to be tightened by a moment of 90 foot-pounds, you pull until the pointer is opposite the number 90 on the scale. The servicing or repair manual on an engine or piece of machinery generally tells you what the torque—or moment of force—should be on each set of nuts or bolts.

The gun pointer uses a COUPLE to elevate and depress the gun barrel. He cranks away at a hand-wheel that has TWO HANDLES. The right-hand handle is on the opposite side of the axle from the left-hand handle—180° apart. Look at figure 36. When he pulls on one handle and pushes on the other, he's producing a COUPLE. But if he lets go the left handle to scratch himself, and cranks only with his right hand, he no longer has a COUPLE—just a simple FIRST-CLASS LEVER! And he'd have to push twice as hard with one hand.

A system of gears—a GEAR TRAIN—transmits the motion to the barrel. A look at figure 37 will help

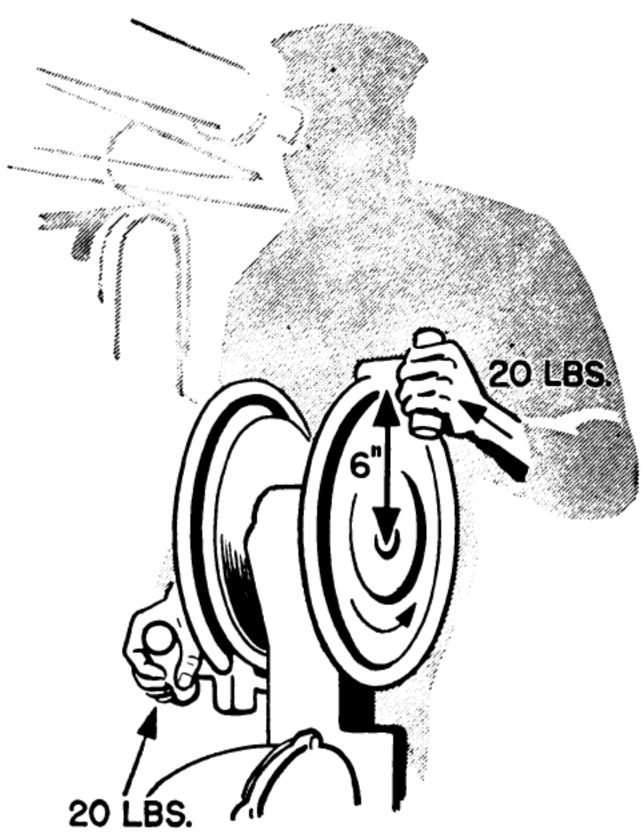


Figure 37.—Developing a torque.

you to figure the forces involved. The radius of the wheel is 6 inches—½ foot—and each handle is being turned with a force of, say, 20 pounds. The moment on the top which tends to rotate the wheel in a CLOCK-

WISE direction is equal to 20 times ½ = 10 ft.-lb. The bottom handle also rotates the wheel in the same direction with an equal moment. Thus the total twist or torque on the wheel is 10 + 10 = 20 ft.-lb. To get the same moment with one hand, applying a 20-pound force, the radius of the wheel would have to be twice as great—12 inches, or one foot. The couple is a convenient arrangement of the wheel-and-axle machine.

# CHAPTER 4

# THE INCLINED PLANE AND THE WEDGE

## THE BARREL ROLL

You have probably watched a driver load barrels on a truck. The truck is backed up to the curb. The driver places a long double plank or ramp from the sidewalk to the tail gate, and then rolls the barrel up the ramp. A 32-gallon barrel may weigh close to 300 pounds when full, and it would be quite a job to lift one up into the truck. Actually, the driver is using a SIMPLE MACHINE called the INCLINED PLANE. You have seen the inclined plane used in in many situations. Cattle ramps, a mountain highway, and the gangplank are familiar examples.

The inclined plane permits you to overcome a large resistance by applying a relatively small force through a longer distance than the load is raised. Look at figure 38. Here you see the driver easing the 300-pound barrel up to the bed of the truck, three feet above the sidewalk. He is using a plank nine feet long. If he didn't use the ramp at all, he'd have to apply a 300-pound force straight up through the three-foot distance. With the ramp, however, he can apply his effort over the entire nine feet of the plank as the barrel is slowly rolled up to a height of three feet. It looks, then, as if he could use a force only three-ninths of 300, or 100 pounds, to do the job. And that is actually the situation.

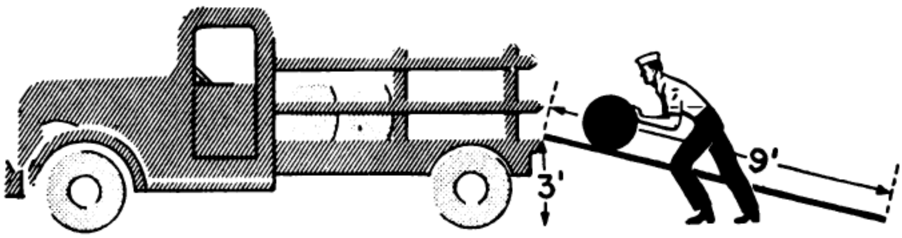



Figure 38.—An inclined plane.

Here's the formula. Remember it from Chapter 1?

$$\frac{L}{l}=\frac{R}{E}$$

In which—$L$ = length of the ramp, measured along the slope,

$l$ = height of the ramp,

$R$ = weight of object to be raised, or lowered,

$E$ = force required to raise or lower object

Now apply the formula to this problem—

In this case, $L=9$ ft.; $l=3$ ft; and $R=300$ lb.

By substituting these values in the formula, you get—

$$\frac{9}{3}=\frac{300}{E}$$

$$9E=900$$

$$E=100 \text{ pounds}$$

Since the ramp is three times as long as its height, the mechanical advantage is THREE. You find the theoretical mechanical advantage by dividing the TOTAL DISTANCE through which your effort is exerted by the VERTICAL DISTANCE through which the load is raised or lowered.

## THE WEDGE

The WEDGE is a special application of the INCLINED PLANE. You have probably used wedges. Abe Lincoln used a wedge to help him split logs into rails for fences. The blades of knives, axes, hatchets, and chisels act as wedges when they are forced into a piece of wood. The wedge is TWO INCLINED PLANES, set base-to-base. By driving the wedge full-length into the material to be cut or split, the material is forced apart a distance equal to the width of the broad end of the wedge. See figure 39.

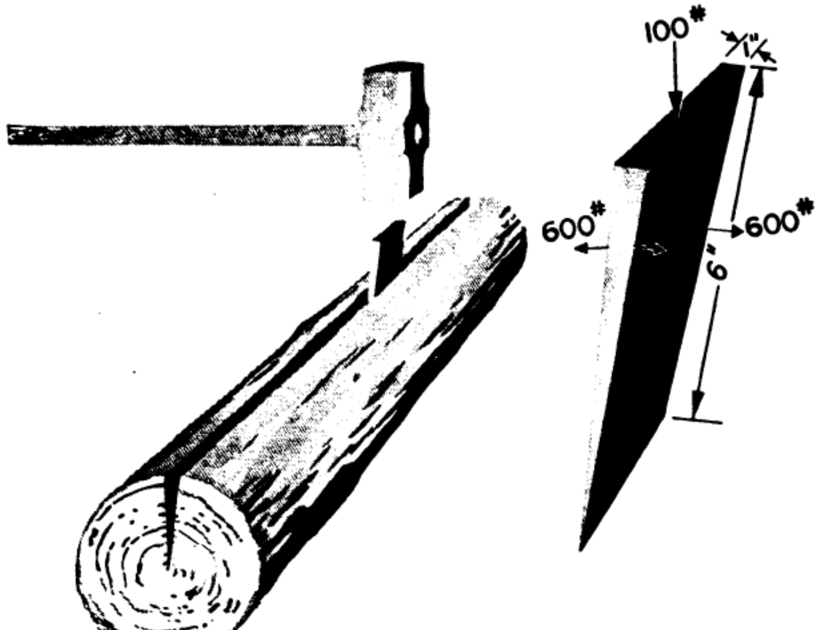



Figure 39.—A wedge.

Long, slim wedges give high mechanical advantage. For example, the wedge of figure 39 has a mechanical advantage of SIX. Their greatest value, however, lies in the fact that you can use them in situations where other simple machines won't work. Imagine the trouble you'd have trying to PULL a log apart with a system of pulleys.

## SUMMARY

Before you look at some of the Navy applications of the inclined plane and the wedge, here's a summary of what to remember from this chapter—

The INCLINED PLANE is a SIMPLE MACHINE that lets you raise or lower heavy objects by applying a SMALL FORCE over a relatively LONG DISTANCE.

The THEORETICAL MECHANICAL ADVANTAGE of the inclined plane is found by dividing the LENGTH of the ramp by the perpendicular HEIGHT that the load will be raised or lowered. The ACTUAL MECHANICAL ADVANTAGE is equal to the weight of the resistance or load, divided by the force that must be used to move the load up the ramp.

The wedge is two inclined planes set base-to-base. It finds its greatest use in CUTTING or SPLITTING materials.

## APPLICATIONS AFLOAT AND ASHORE

The most common use of the incline plane in the Navy is the GANGPLANK. Going aboard the ship by gangplank, illustrated in figure 40, is certainly easier than climbing up a sea ladder. And you appreciate the M. A. of the gangplank even more when you have to carry your sea bag or a case of prunes aboard.

Remember that HATCH DOG in figure 9. The dog that's used to secure a door not only takes advantage of the LEVER principle, but—if you look sharply—you can see that the dog seats itself on a STEEL WEDGE which is welded to the door. As the dog slides upward along this wedge, it forces the door tightly shut. This is an inclined plane, with its length about eight times its thickness. That means you get a theoretical mechanical advantage of eight. You figured, in Chapter 1, that you got a mechanical advantage of four from the lever action of the dog—so the overall mechanical advantage is 8 times 4 or 32, neglecting friction. Not bad for such a simple gadget, is it? Push down with 50 pounds heave on the handle and you squeeze the door shut with a force of 1,600 pounds, on that dog. You'll find the damage-control parties using wedges by the dozen to shore up bulkheads and decks. A few sledge-hammer blows on a wedge will tighten up balks and shoring tighter than Dick's hatband.

Chipping scale or paint off steel is a tough job.

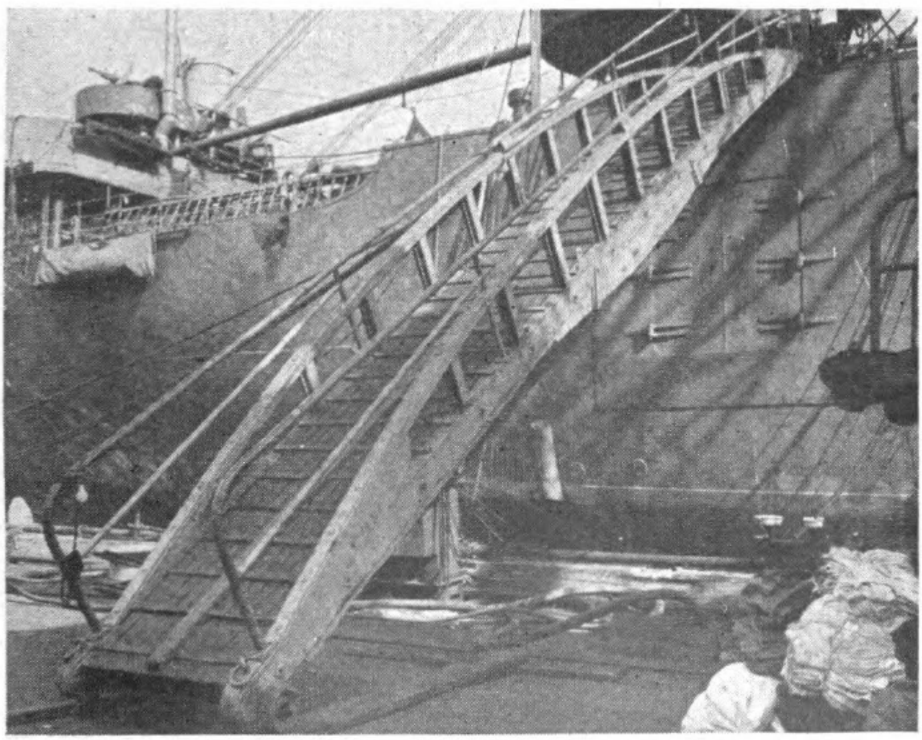


Figure 40.—The gangplank is an inclined plane.

However, the job is made a lot easier with a COMPRESSED AIR CHISEL. The wedge-shaped cutting edge of the chisel gets in under the metal or the paint, and exerts great pressure to lift the metal or paint layer. The chisel bit is another application of the inclined plane.

## CHAPTER 5

# THE SCREW

### A MODIFIED INCLINED PLANE

The SCREW is a SIMPLE MACHINE that has many uses. The vise on a work-bench makes use of the great mechanical advantage of the screw. So do the screw clamps used to hold a piece of furniture together while it is being glued. And so do many automobile jacks and even the food grinder in the kitchen at home.

A SCREW is a modification of the INCLINED PLANE. Cut a sheet of paper in the shape of a right triangle—an inclined plane. Wind it around a pencil, as in figure 42. Then you can see that the SCREW is actually an INCLINED PLANE WRAPPED AROUND A CYLINDER. As the pencil is turned, the paper is wound up so that its hypotenuse forms a SPIRAL THREAD similar to the thread on the screw shown at the right. The PITCH of the screw, and of the paper, is the distance between identical points on the same threads, and measured along the length of the screw.

In order to understand how the screw works, look at figure 43. Here you see a JACK SCREW of the type that is used to raise a house or a piece of heavy machinery. The jack has a lever handle with a length $r$. If you pull the lever handle around one turn, its outer end has described a circle. The circumference

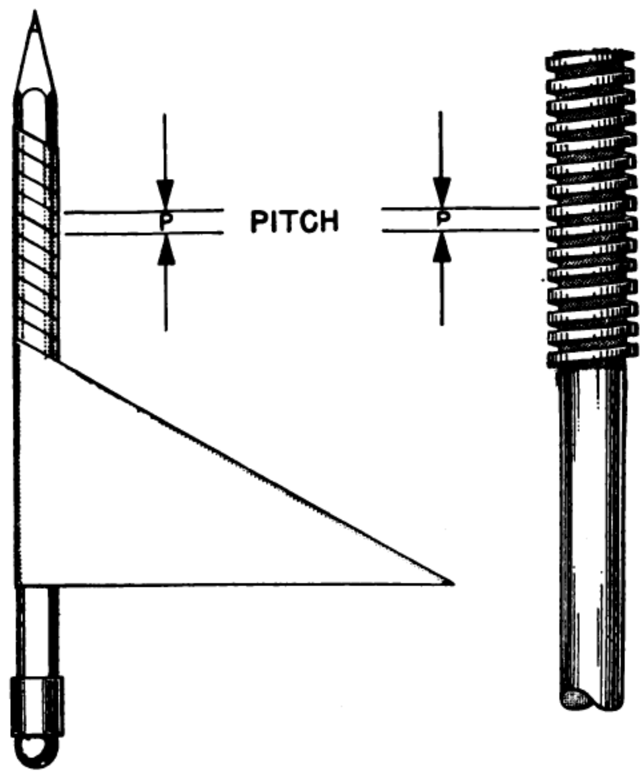


Figure 42.—A screw is an inclined plane in spiral form.

of this circle is equal to $2\pi r$. (You remember that $\pi$ equals 3.14, or $\frac{22}{7}$). That is the distance, or the LEVER ARM, through which your effort is applied.

At the same time, the screw has made one revolution, and in doing so has been raised a height equal to its pitch $p$. You might say that ONE FULL THREAD has come up out of the base. At any rate, the load has been raised a distance $p$.

Remember that the theoretical mechanical advantage is equal to the distance through which the effort or pull is applied, divided by the distance the resistance or load is moved. Assuming a 2-foot—24″—

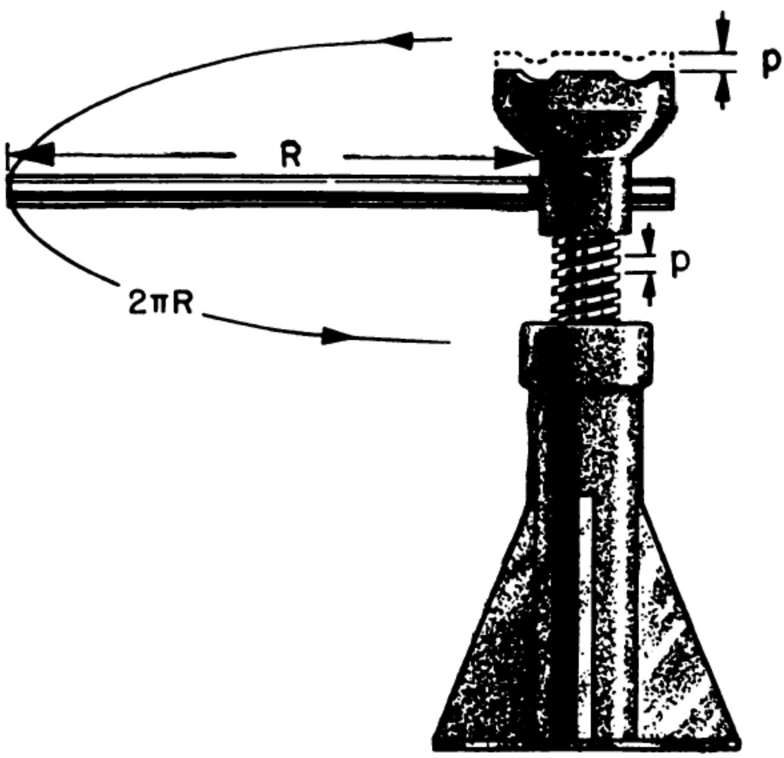



Figure 43.—A jack screw.

length for the lever arm, and a ¼-inch pitch for the thread, you can find the theoretical mechanical advantage by the formula—

$$M.\ A. = \frac{2\pi r}{p}$$

in which

$r$=length of handle=24 inches

$p$=pitch, or distance between corresponding points on successive threads=¼-inch.

Substituting,

$$T.\ M.\ A. = \frac{2 \times 3.14 \times 24}{\frac{1}{4}} = \frac{150.72}{\frac{1}{4}} = 602.88$$

A 50-pound pull on the handle would result in a THEORETICAL LIFT of 50×602 or about 30,000 pounds. Fifteen tons for fifty pounds.

But jacks have considerable friction loss. The threads are cut so that the force used to overcome friction is greater than the force used to do useful work. If the threads were not cut this way, if no friction were present, the weight of the load would cause the jack to spin right back down to the bottom as soon as you released the handle.

## THE MICROMETER

In using the jack, you exerted your effort through a distance of $2\pi r$, or 150 inches, in order to raise the screw ¼ inch. It takes a lot of CIRCULAR MOTION to get a small amount of STRAIGHT-LINE MOTION from the head of the jack. You will use this point to advantage in the MICROMETER, which is a useful device for making accurate small measurements, measurements of a few thousandths of an inch.

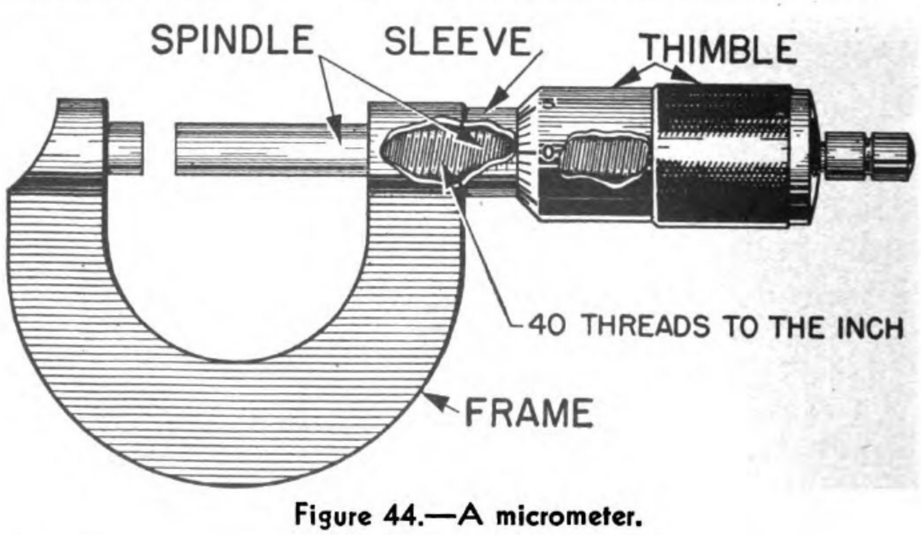



Figure 44.—A micrometer.

In figure 44, you see a cutaway view of a MICROMETER. The THIMBLE turns freely on the SLEEVE, which is rigidly attached to the micrometer FRAME. The SPINDLE is attached to the thimble, and is fitted with screw threads which move the spindle and thimble to right or left in the sleeve when you rotate the thimble. These screw threads are cut 40 threads to the inch. Hence ONE TURN of the thimble moves the spindle and thimble 1/40 inch. This represents one of the smallest divisions on the micrometer. Four of these small divisions make 4/40 of an inch, or 1/10 inch. Thus the distance from 0 to 1 or 1 to 2 on the sleeve represents 1/10 or 0.1 inch.

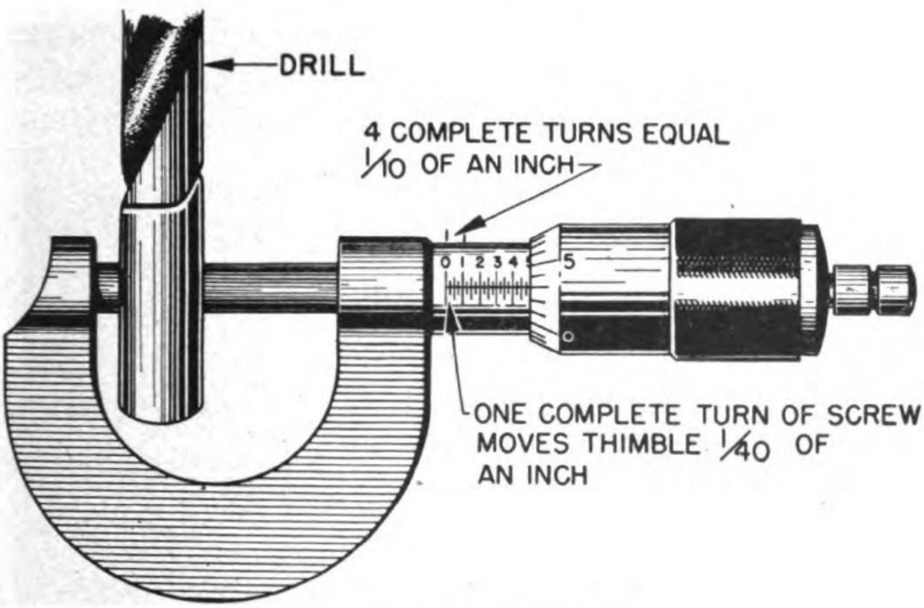



**Figure 45.—Taking turns.**

To allow even finer measurements, the thimble is divided into 25 equal parts laid out by graduation marks around its rim, as shown in figure 45. If you turn the thimble through 25 of these equal parts, you have made one complete revolution of the screw, which represents a lengthwise movement of 1/40 of an inch. Now, if you turn the thimble ONE of these units on its scale, you have moved the spindle a distance of 1/25 of 1/40 inch, or 1/1000 of an inch—0.001 inch.

The micrometer in figure 50 reads 0.503 inch, which is the true diameter of the half-inch drill-bit shank being measured. This tells you that the diameter of this particular bit is 0.003 inch greater than its nominal diameter of 1/2 inch—0.500″.

Because you can make such accurate measurements with this instrument, it is indispensable in every machine shop.

## SUMMARY

Look over the basic ideas you have learned from this chapter, and then see how the Navy uses this simple machine—the SCREW.

The screw is a modification of the inclined plane—modified to give you a HIGH MECHANICAL ADVANTAGE.

The theoretical mechanical advantage of the screw can be found by the formula $M.\,A.=\frac{2\pi r}{p}$. As in all machines, the actual mechanical advantage equals the RESISTANCE DIVIDED BY THE EFFORT.

In many applications of the screw, you make use of the large amount of friction that is commonly present in this simple machine.

By the use of the screw, large amounts of circular motion are reduced to very small amounts of straight-line motion.

## APPLICATIONS AFLOAT AND ASHORE

It's a tough job to pull a rope or cable up tight enough to get ALL the slack out of it. But you can

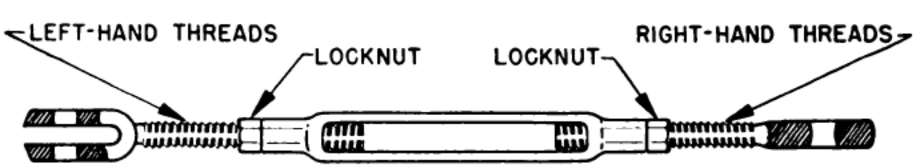



Figure 46.—A turnbuckle.

do it. Use a TURNBUCKLE. The turnbuckle is an application of the screw. See figure 46. If you turn it in one direction, it takes up the slack in a cable. Turning it the other way slacks off on the cable.

You'll notice that one bolt of the turnbuckle has LEFT-HAND THREADS, and the other bolt has RIGHT-HAND threads. Thus, when you turn the turnbuckle to tighten up the line, BOTH bolts tighten up. If both bolts were RIGHT-HAND THREAD—STANDARD THREAD—one would tighten while the other one loosened an equal amount. Result—no change in cable-slack. Most turnbuckles have the screw threads cut to provide a large amount of frictional resistance to keep the turnbuckle from unwinding

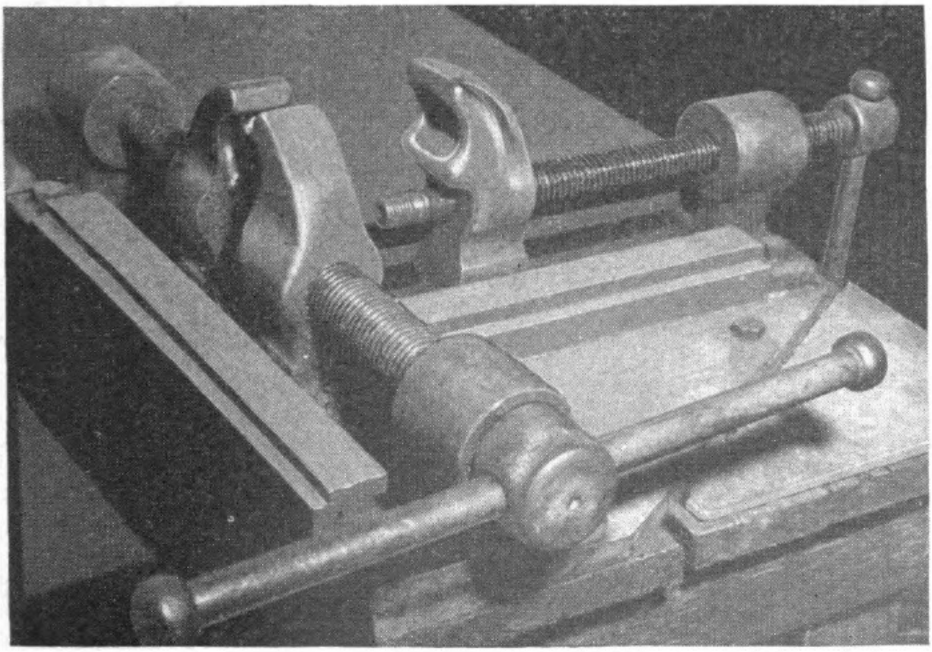


Figure 47.—A rigger's vise.

under load. In some cases, the turnbuckle has a lock nut on each of the screws to prevent slipping. You'll find turnbuckles used in a hundred different ways afloat and ashore.

Ever wrestled with a length of wire rope? Obstinate and unwieldy, wasn't it? Riggers have dreamed up tools to help subdue wire rope. One of these tools—the RIGGER'S VISE—is shown in figure 47. This rigger's vise uses the great mechanical advantage of the screw to hold the wire rope while the crew splices a THIMBLE—a reinforced loop—onto the end of the cable. Rotating the handle causes the jaw on that screw to move in or out along its grooves. This machine is a modification of the vise on a work bench. Notice the right-hand and left-hand screws on the left-hand clamp.

Figure 48 shows you another use of the SCREW. Suppose you want to stop a winch with its load suspended in mid-air. To do this, you need a BRAKE. The brake on most anchor or cargo winches consists of a metal band that encircles the brake drum. The two ends of the band are fastened to nuts connected

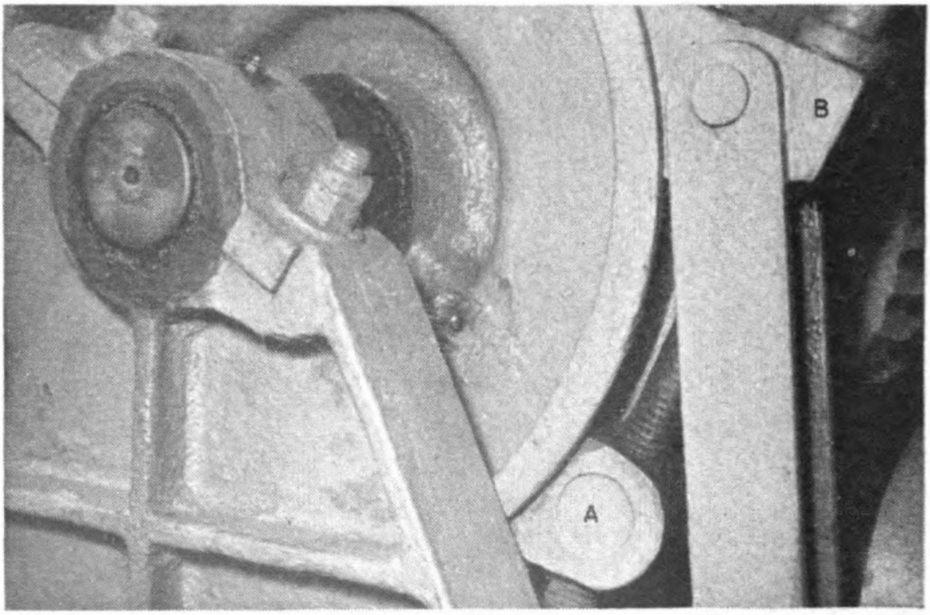



**Figure 48.—A friction brake.**

by a screw attached to a handwheel. As you turn the handwheel, the screw pulls the lower end of the band *A* up toward its upper end *B*. The huge M. A. of the screw puts the squeeze on the drum, and all rotation of the drum is stopped.

One type of steering gear used on many small ships—and as a spare steering system on some larger ships—is the SCREW GEAR. Figure 49 shows you that the wheel turns a long threaded shaft. Half the threads—those nearer the wheel end of this shaft—are RIGHT-HAND THREADS. The other half of the threads—those farther from the wheel—are LEFT-HAND THREADS. The nut *A* has a right-hand thread, and nut *B* has a left-hand thread. Notice that the cross head which turns the rudder is connected to the nuts by two STEERING ARMS. If you stand in front of the wheel and turn it in a CLOCKWISE direction—to your right—arm *A* moves forward and arm B moves backward. This turns the rudder counter-clockwise, so that the ships swings in the direction you turn the wheel. There is a great mechanical advantage to this steering mechanism.

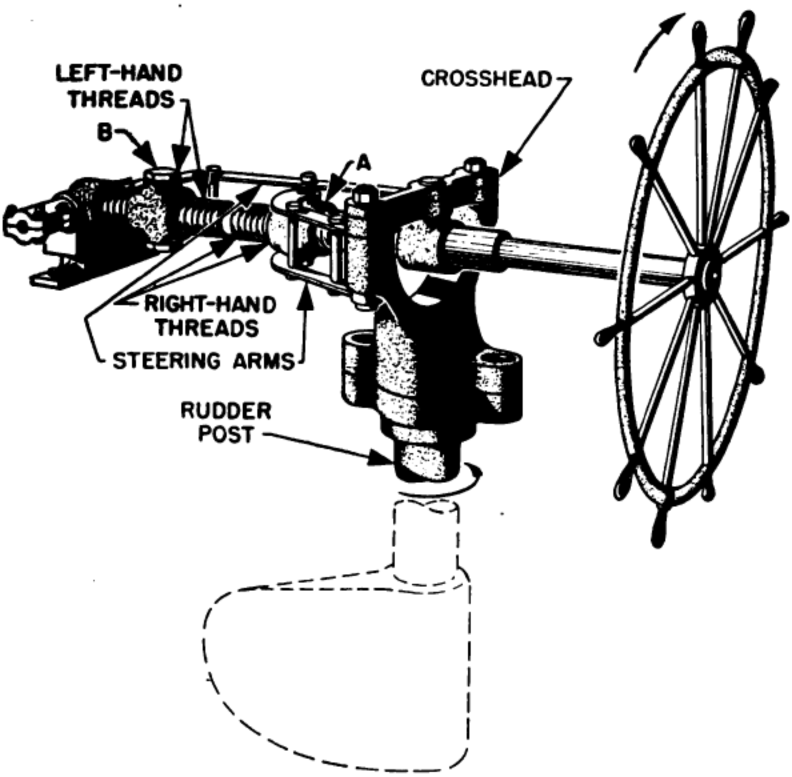



**Figure 49.—The screw gear gives a tremendous mechanical advantage.**

Figure 50 shows you another practical use of the SCREW. The QUADRANT DAVIT makes it possible for two men to put a large life boat over the side with little effort. The operating handle is attached to a threaded screw which passes through a traveling nut. If the operating handle is cranked in a counter-clockwise direction (as you face outboard), the nut travels outward along the screw. The traveling nut is fastened to the davit arm by a swivel. The davit arm and the boat swing outboard as a result of the

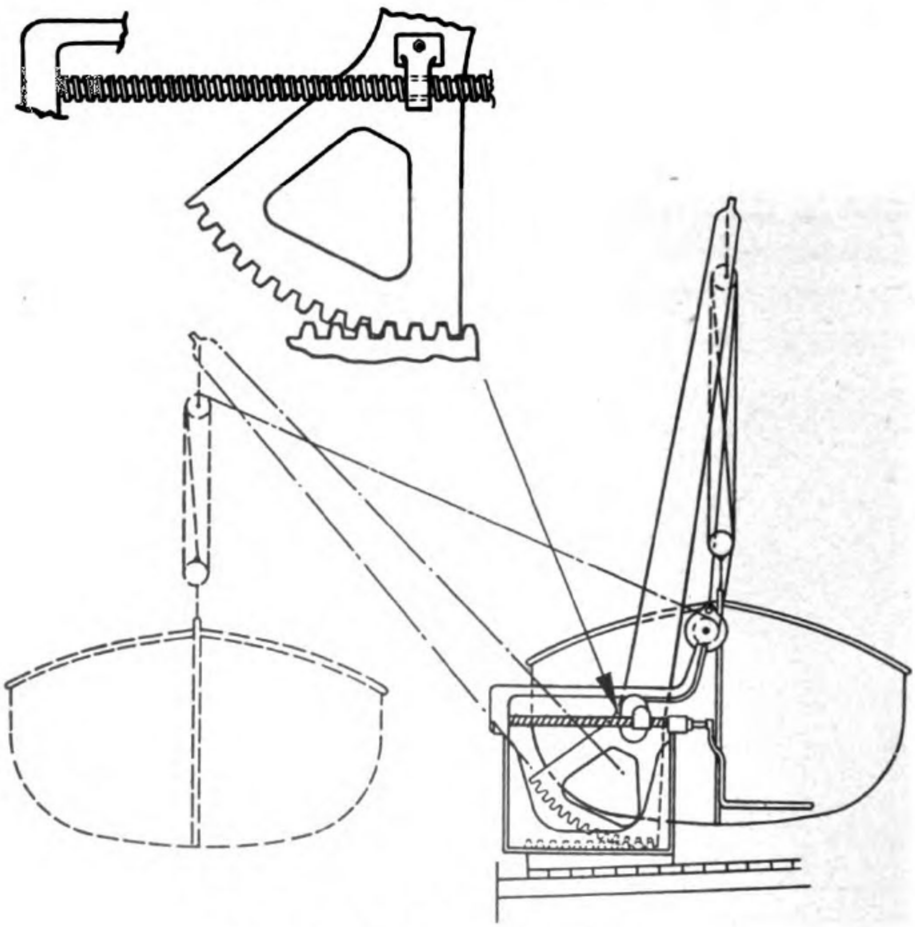
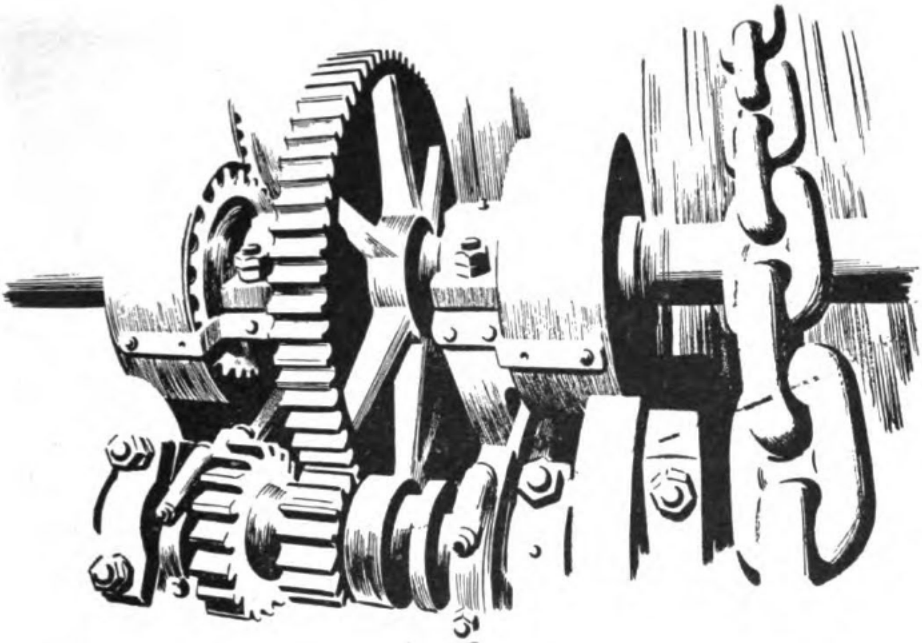


Figure 50.—The quadrant davit.

outward movement of the screw. The thread on that screw is the self-locking type—if you let go of the handle the nut remains locked in position.



## CHAPTER 6

# GEARS

### A TOPIC WITH TEETH IN IT

Did you ever take a clock apart to see what made it tick? Of course you came out with some parts left over when you got it back together again. And they probably included a few GEAR WHEELS. Gears are used in many machines. Frequently the gears are hidden from view in a protective case filled with grease or oil, and you may not see them.

Remember hanging around the kitchen waiting to lick the bowl when Mom was beating up the frosting for a cake? That egg beater gives you a simple demonstration of the three things that gears do. They can change the DIRECTION OF MOTION; increase or decrease the SPEED OF THE APPLIED MOTION; and magnify or reduce the FORCE WHICH YOU APPLY. Gears also give you a POSITIVE DRIVE. There can be, and usually is, creep or slip in a belt drive. But gear teeth are always in mesh, and there can be no creep and slip.

Follow the DIRECTIONAL CHANGES in figure 51. The crank handle is turned in the direction indicated by the arrow— clockwise, when viewed from the right. The 32 teeth on the large vertical wheel *A* mesh with the 8 teeth on the right-hand horizontal wheel *B*, which rotates as indicated by the arrow. Notice that as *B* turns in a CLOCKWISE direction, its teeth mesh with those of wheel *C* and cause wheel *C* to revolve in the OPPOSITE direction. The rotation of

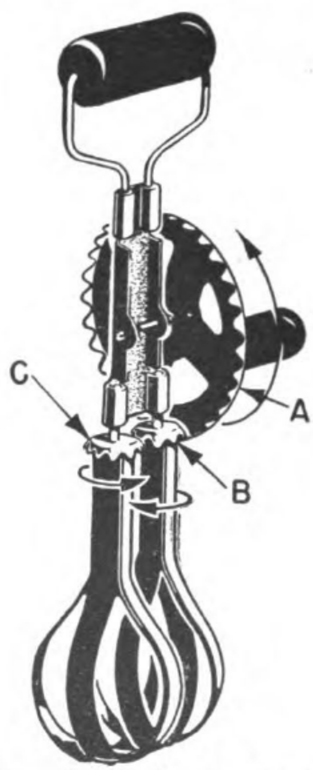



**Figure 51.—A simple gear arrangement.**

the crank handle has been transmitted by GEARS to the beater blades, which also rotate.

Now figure out how the gears change the SPEED OF MOTION. There are 32 teeth on gear *A* and 8 teeth on gear *B*. But the gears mesh, so that one complete revolution of *A* results in four complete revolutions of gear *B*. And since gears *B* and *C* have the same number of teeth, one revolution of *B* results in one revolution of *C*. Thus the blades revolve four times as fast as the crank handle.

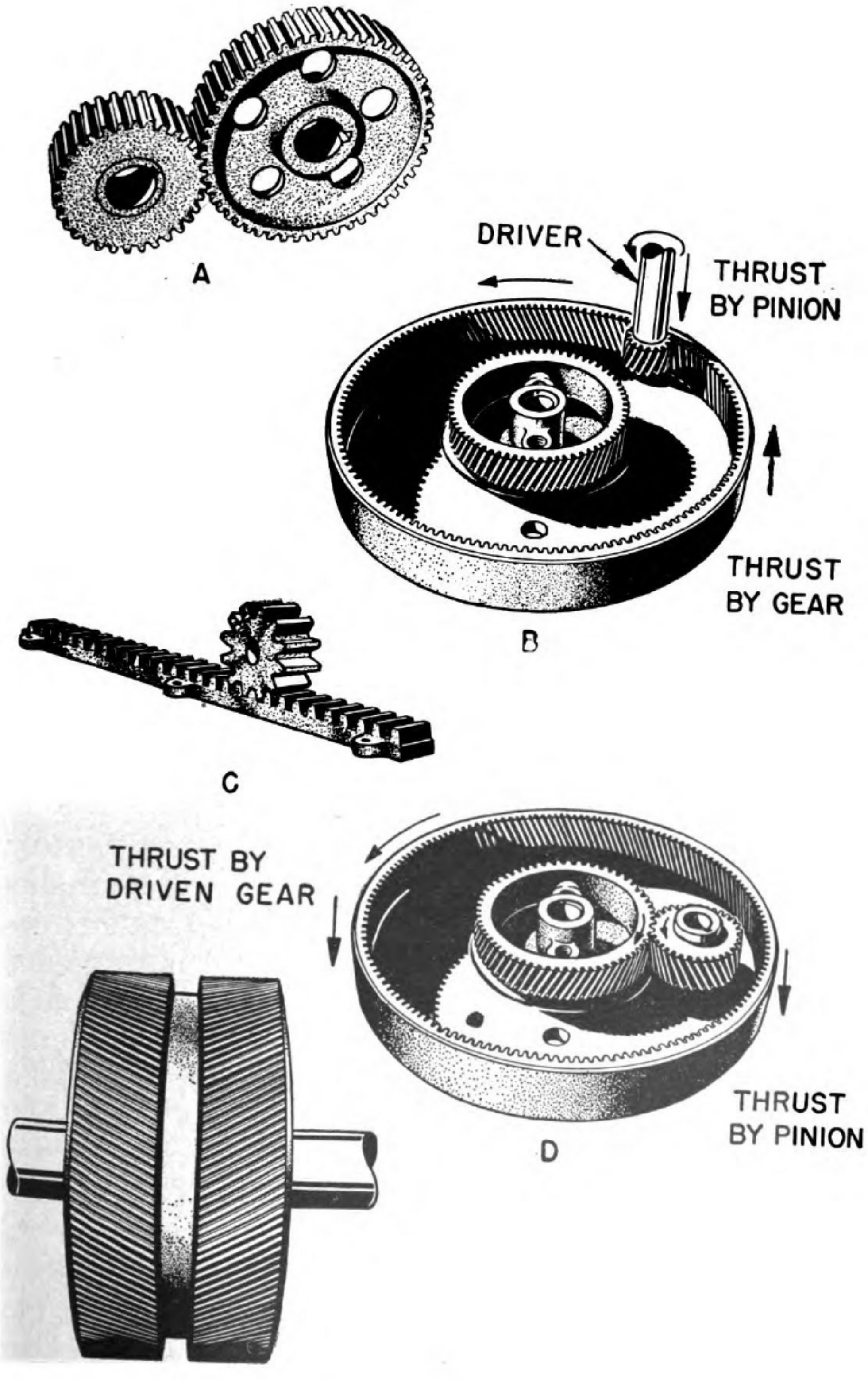



Figure 52.—You'll see plenty of these.

In Chapter 1 you learned that third-class levers increase SPEED at the expense of FORCE. The same things happens with this egg beater. The MAGNITUDE of the force is changed. The force required to turn the handle is greater than the force applied to the frosting by the blades. Therefore a mechanical advantage of LESS THAN ONE results.

## TYPES OF GEARS

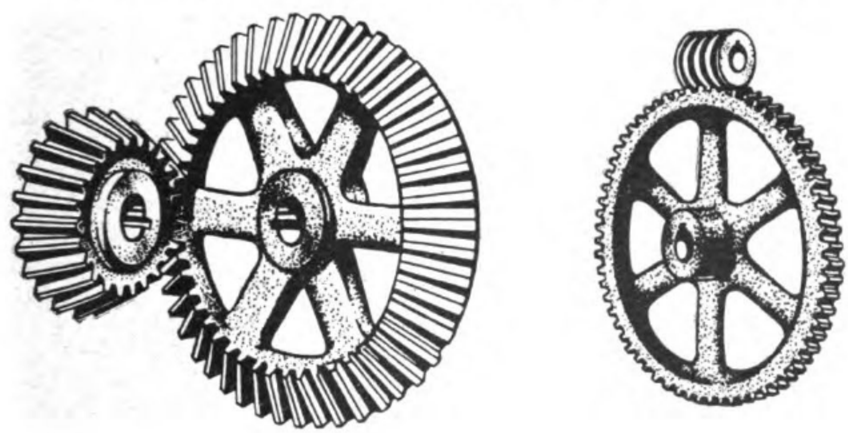
Gears, like people, have names. You will want to know the names of some of these gears, and how the various types are used. In figure 52 you see some gears that are used when the driving shaft and the driven shaft are parallel. Figure 52A shows two EXTERNAL SPUR GEARS, so named because they are in EXTERNAL contact. This arrangement of teeth is the one most commonly used.

In 52B you see two spur gears in INTERNAL contact—the teeth on the large gear are cut on the INSIDE of its rim. When INTERNAL GEARS are used, the driven gear rotates in the SAME DIRECTION as the driver. There is NO REVERSAL OF ROTATION, such as there is with EXTERNAL gears. The smaller of the two spur gears is usually called a PINION. The RACK AND PINION in 52C are both spur gears. The rack may be considered as a piece cut from a gear with an extremely large radius. The rack-and-pinion arrangement is useful in changing circular motion into straight-line motion.

When spur gears mesh, the load is carried by the two teeth in contact at that instant. This results in the force being transferred from one gear to another by a series of sharp jerks. To avoid this and to provide for smoother operation, you can use helical gears, shown in figures 52B and 52D. One disadvantage of this helical spur gear is the tendency of each gear to THRUST or push axially on its shaft. The direction of thrust is indicated by the arrows.

It is necessary to put a special THRUST BEARING at the end of the shaft to counteract the thrust.

Thrust bearings are not needed if HERRINGBONE GEARS like those shown in 52*E* are used. Since the teeth on each half of the gear are cut in opposite directions, each half of the gear develops a thrust which counterbalances that of the other half. You'll find herringbone gears used mostly on heavy machinery.



**BEVEL GEARS** **WORM AND SPUR GEAR**

**Figure 53.—Other gears.**

When the shafts are NOT parallel, gears of the types shown in figure 53 are used. Those shown at the left are BEVEL GEARS. The right-hand drawing of figure 53 shows a WORM GEAR, which is really a combination of a screw and a spur gear. One full revolution of the worm turns the spur gear ahead a distance equal to one tooth of the gear. If there are 40 teeth on the spur gear, the worm will have to revolve 40 times in order to rotate the gear one revolution. Tremendous mechanical advantages can be obtained with this arrangement.

The worm may be SINGLE-THREADED, so that the spur gear is moved ahead one tooth per revolution of the worm. Or the worm may be DOUBLE-THREADED or TRIPLE-THREADED. Then the spur gear will be moved ahead TWO teeth or THREE teeth per revolution of the worm.

Worm drives can also be designed so that only the worm is the DRIVER—the spur cannot drive the worm. On a hoist, for example, you can raise or lower the load by pulling on the chain which turns the worm. But if you let go of that chain, the load cannot drive

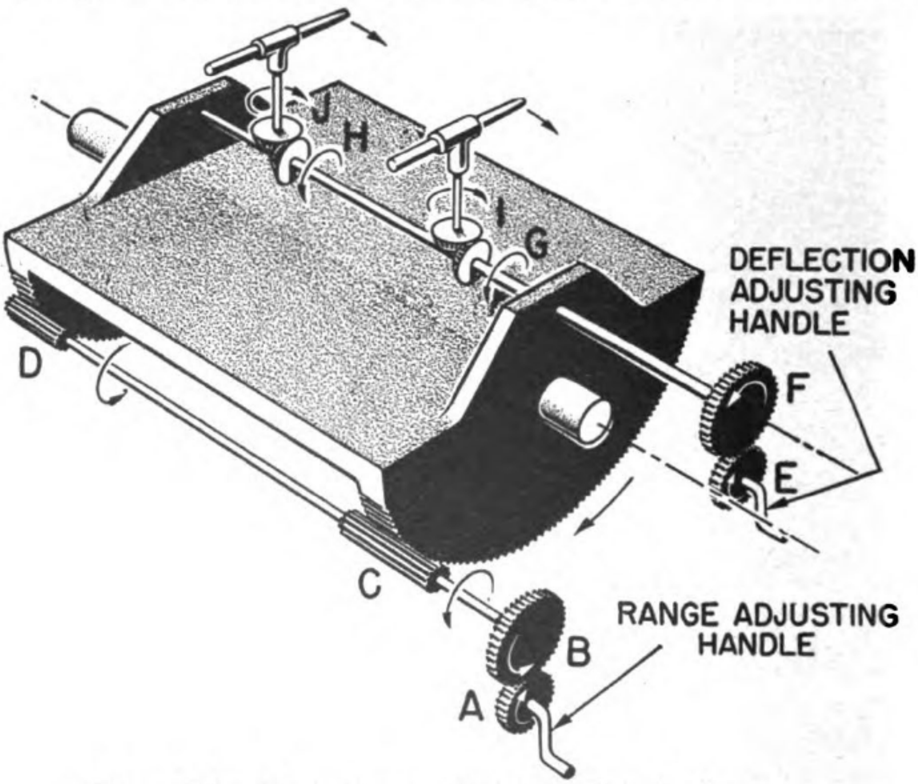



**Figure 54.—Gears change direction of applied motion.**

the spur gear and let the load drop to the deck. This is a NON-REVERSING WORM DRIVE.

## CHANGING DIRECTION WITH GEARS

No doubt you know that the crankshaft in an automobile engine can turn in only one direction. If you want the car to go backwards, the EFFECT of the engine's rotation must be reversed. This is done by a reversing gear in the transmission, not by reversing the direction in which the crankshaft turns.

A study of figure 54 will show you how gears are used to change the direction of motion. This is a schematic diagram of the sight mounts on a Navy gun. If you crank the range-adjusting handle *A* in a clockwise direction the gear *B* directly above it is made to rotate in a counterclockwise direction. This motion causes the two pinions *C* and *D* on the shaft to turn in the same direction as gear *B* against the teeth cut in the bottom of the table. The table is tipped in the direction indicated by the arrow.

As you turn the deflection-adjusting handle *E* in a clockwise direction the gear *F* directly above it turns in the opposite direction. Since the two bevel gears *G* and *H* are fixed on the shaft with *F*, they also turn. These bevel gears, meshing with the horizontal bevel gears *I* and *J*, cause *I* and *J* to swing the front ends of the telescopes to the right. Thus with a simple system of gears, it is possible to keep the two tele-

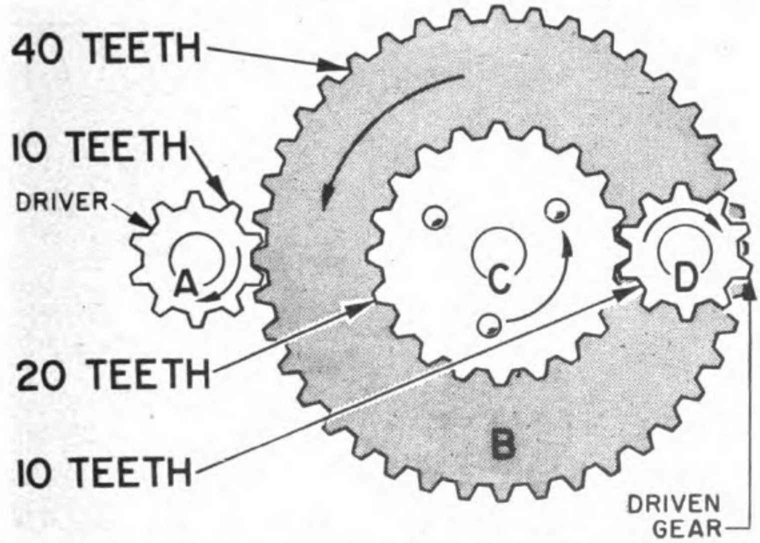


Figure 55.—Gears can change the speed of applied motion.

scopes pointed at a moving target. In this and many other practical applications, gears serve one purpose—to CHANGE THE DIRECTION OF MOTION.

## CHANGING SPEED

As you've already seen in the egg-beater, gears can be used to change the speed of motion. Another example of this use of gears is found in your clock or watch. The mainspring slowly unwinds and causes the hour hand to make one revolution in 12 hours. Through a series—or TRAIN—of gears, the minute hand makes one revolution each hour, while the second hand goes around once per minute.

Figure 55 will help you to understand how speed changes are made possible. Wheel *A* has 10 teeth which mesh with the 40 teeth on wheel *B*. Wheel *A* will have to rotate FOUR times to cause *B* to make ONE revolution. Wheel *C* is rigidly fixed on the same shaft with *B*. Thus *C* makes the same number of

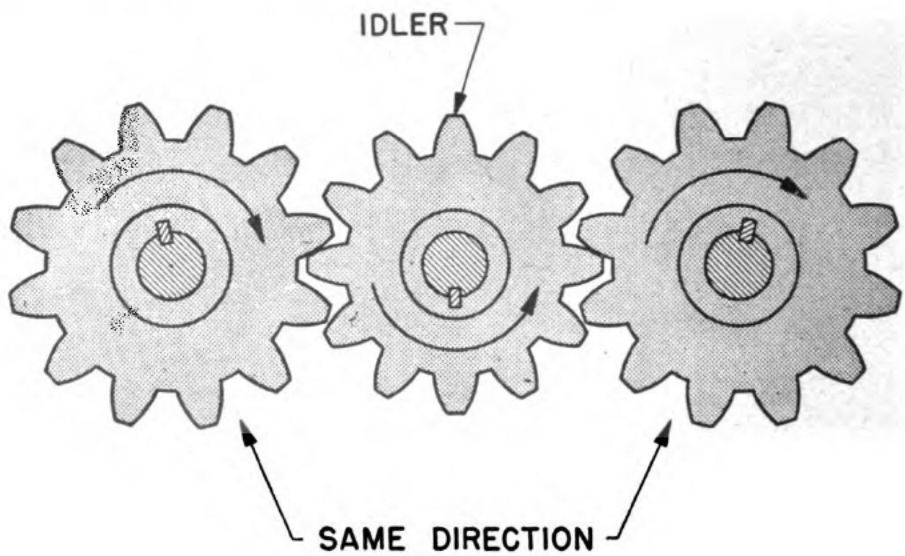



**Figure 56.—An idler gear.**

revolutions as *B*. However, *C* has 20 teeth, and meshes with wheel *D* which has only 10 teeth. Hence, wheel *D* turns twice as fast as wheel *C*. Now, if you turn *A* at a speed of four revolutions per second, *B* will be rotated at one revolution per second. Wheel *C* also moves at one revolution per second, and causes *D* to turn at two revolutions per second. You get out two revolutions per second after having put in four revolutions per second. Thus the over-all speed reduction is $\frac{2}{4}$—or $\frac{1}{2}$—which means that you get half the speed out of the last DRIVEN wheel that you put into the first DRIVER wheel.

You can solve any gear speed-reduction problem with this formula—

$$S_2 = S_1 \times \frac{T_1}{T_2},$$

where

$S_1$=speed of FIRST shaft in train
$S_2$=speed of LAST shaft in train
$T_1$=product of teeth on all DRIVERS
$T_2$=product of teeth on all DRIVEN gears

Now use the formula on the gear train of figure 57.

$$S_2 = S_1 = \times \frac{T_1}{T_2} = 4 \times \frac{10 \times 20}{40 \times 10} = \frac{800}{400} = 2 \text{ revs. per sec.}$$

Almost any increase or decrease in speed can be obtained by choosing the correct gears for the job.

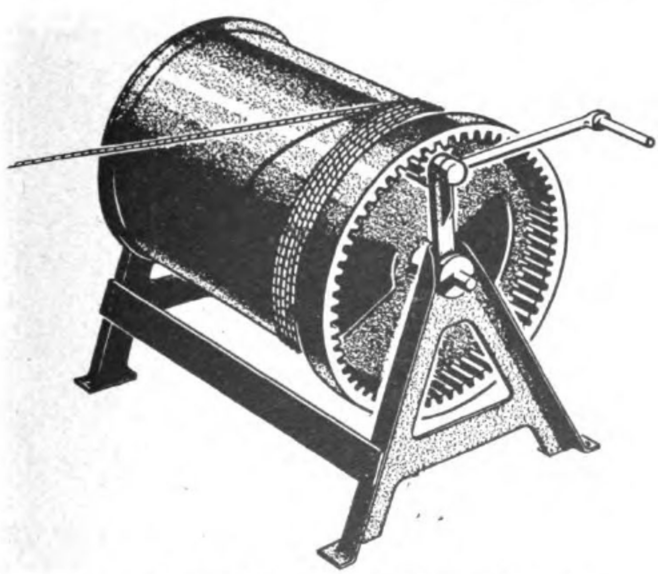


Figure 57.—This magnifies your effort.

For example, the turbines on a ship have to turn at high speeds—say 5,800 rpm—if they are going to be efficient. But the propellers, or screws, must turn rather slowly—say 195 rpm—to push the ship ahead with maximum efficiency. So, a set of reduction gears is placed between the turbines and the propeller shaft.

When two external gears mesh, they rotate in opposite directions. Often you'll want to avoid this. Put a third gear, called an IDLER, between the driver and the driven gear. But don't let this extra gear confuse you on speeds. Just neglect the

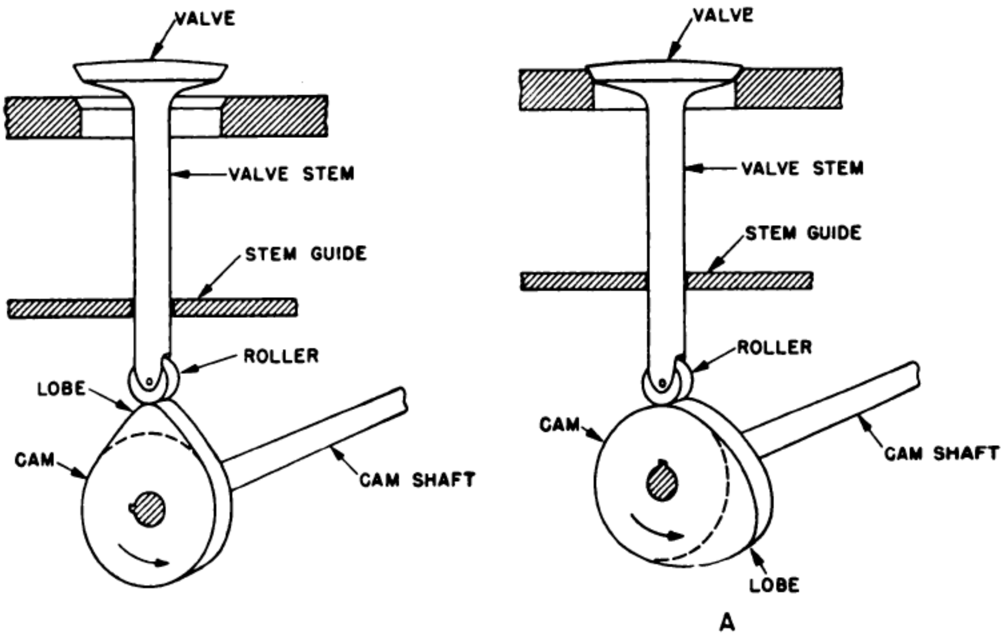



Figure 58.—Cam-driven valve.

idler entirely. It doesn't change the GEAR RATIO at all, and the formula still applies. The idler merely makes the driver and its driven gear turn in the same direction. Figure 56 will show you how this works.

## MAGNIFYING FORCE WITH GEARS

GEAR TRAINS are used to increase the mechanical advantage. In fact, wherever there is a SPEED REDUCTION, the effect of the effort you apply is multiplied. Look at the cable winch in figure 57. The crank arm is 30 inches long, and the drum on which the cable is wound has a 15-inch radius. The small pinion gear has 10 teeth, which mesh with the 60 teeth on the internal spur gear. You will find it easier to figure the mechanical advantage of this machine if you think of it as TWO machines.

First, figure out what the gear and pinion do for you. The theoretical mechanical advantage of ANY arrangement of two meshed gears can be found by the following formula—

$$M.\ A.\ (\text{theoretical}) = \frac{T_o}{T_a}$$

In which, $T_o$ = number of teeth on driven gear;
$T_a$ = number of teeth on driver gear.
In this case, $T_o = 60$ and $T_a = 10$. Then,

$$M.\ A.\ (\text{theoretical}) = \frac{T_o}{T_a} = \frac{60}{10} = 6$$

Now, for the other part of the machine, which is a simple wheel-and-axle arrangement consisting of the CRANK arm and the DRUM. The theoretical mechanical advantage of this can be found by dividing the

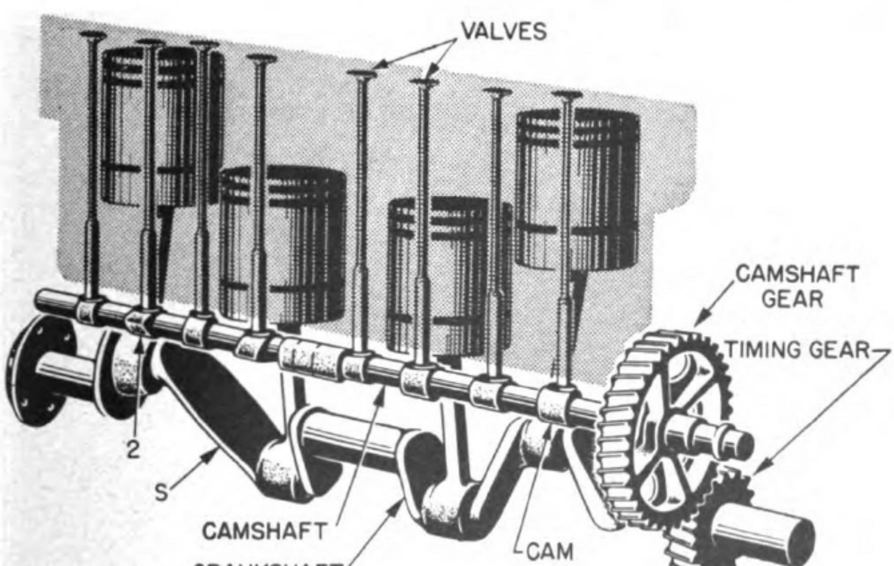



**Figure 59.—Automobile valve gear.**

distance the effort moves—$2\pi R$—in making one complete revolution, by the distance the cable is drawn up in one revolution of the drum—$2\pi r$.

$$M.\ A.\ (\text{theoretical}) = \frac{2\pi R}{2\pi r} = \frac{R}{r} = \frac{30}{15} = 2$$

You know that the total, or over-all, theoretical mechanical advantage of a compound machine is equal to the PRODUCT of the mechanical advantages of the several simple machines that make it up. In this case you considered the winch as being TWO MACHINES—one having an *M. A.* of 6, and the other an *M. A.* of 2. Therefore, the OVER-ALL THEORETICAL MECHANICAL ADVANTAGE of the winch is $6 \times 2$, or 12. Since friction is always present, the ACTUAL mechanical advantage may be only 7 or 8. Even so, by applying a force of 100 pounds on the handle, you could lift a load of 700 or 800 pounds.

## CAMS

You use gears to produce circular motion. But you often want to change circular motion into UP-AND-DOWN or STRAIGHT-LINE MOTION. You can use CAMS to do this. For example—

The shaft in figure 58*A* is turned by the gear. A CAM is keyed to the shaft and turns with it. The cam has an irregular shape which is designed to move the valve stem up and down, giving the valve a straight-line motion as the cam shaft rotates.

In figure 58*B* you see what happens when the shaft has turned to bring the high point—the LOBE—of the cam under the valve stem. The valve is wide open.

A set of cams, two to a cylinder, and driven by timing gears from the crankshaft operates the exhaust and intake valves on the gasoline automobile engine as shown in figure 59. Cams are widely used in machine tools and other devices to make rotating gears and shafts do up-and-down work.

## IT ADDS UP THIS WAY

These are the important points you should keep in mind about GEARS—

Gears can do a job for you by CHANGING the DIRECTION, SPEED, or SIZE of the force which you apply.

When two external gears mesh, they always turn in OPPOSITE directions. You can make them turn in the same direction by placing an IDLER GEAR between the two.

The product of the number of teeth on each of the DRIVER GEARS, divided by the product of

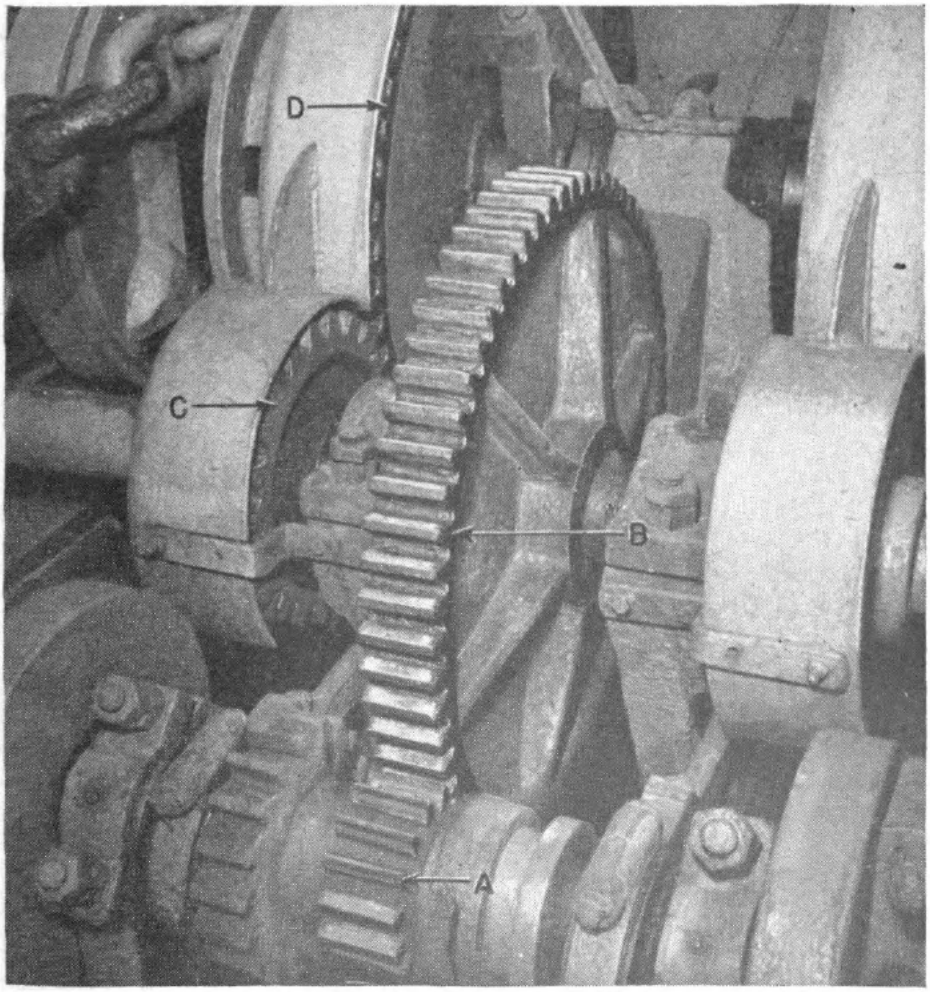


Figure 60.—An anchor winch.

the number of teeth on each of the DRIVEN GEARS, gives you the SPEED RATIO of any gear train.

The theoretical mechanical advantage of any gear train is the product of the number of teeth on the DRIVEN GEAR wheels, divided by the product of the number of teeth on the DRIVER GEARS.

The overall theoretical mechanical advantage of a COMPOUND MACHINE is equal to the PRODUCT

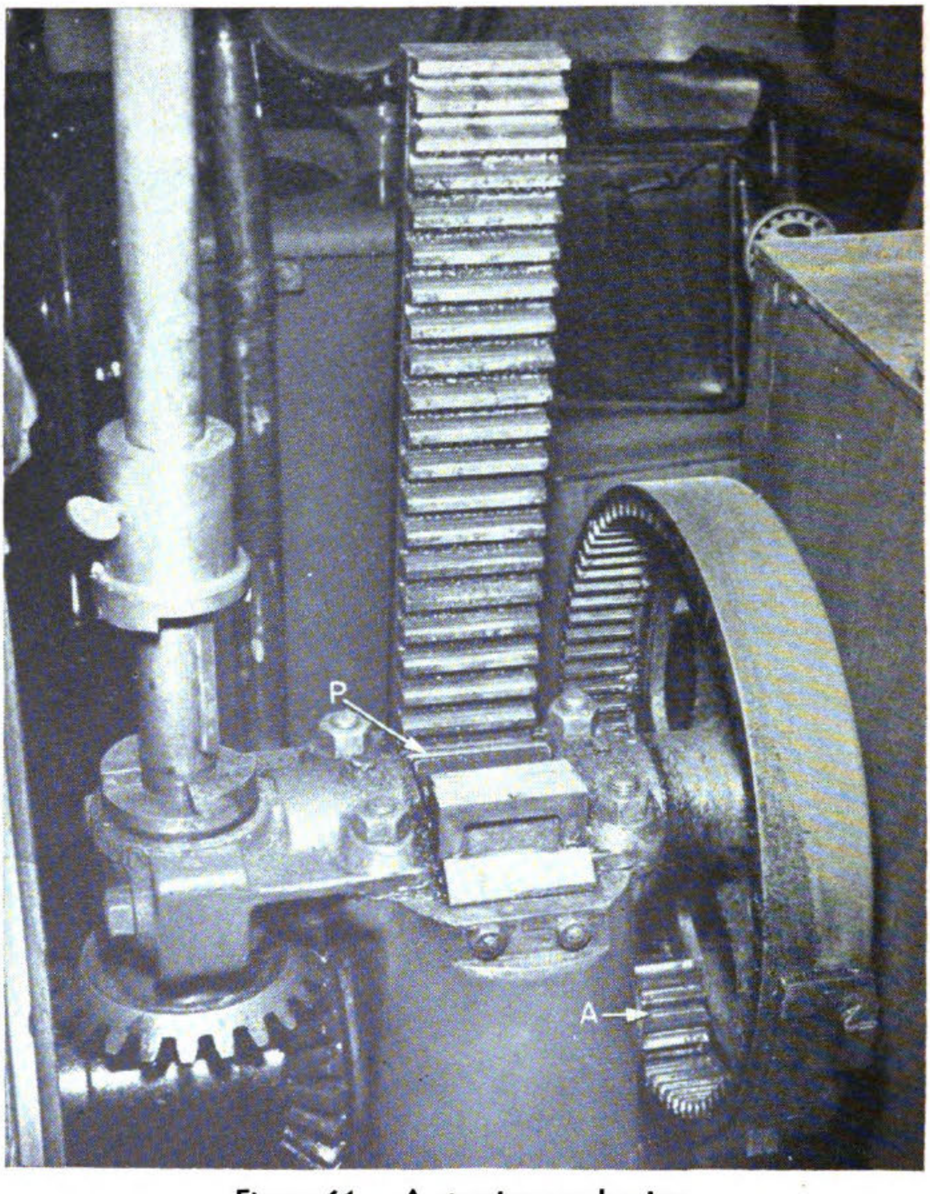


Figure 61.—A steering mechanism.

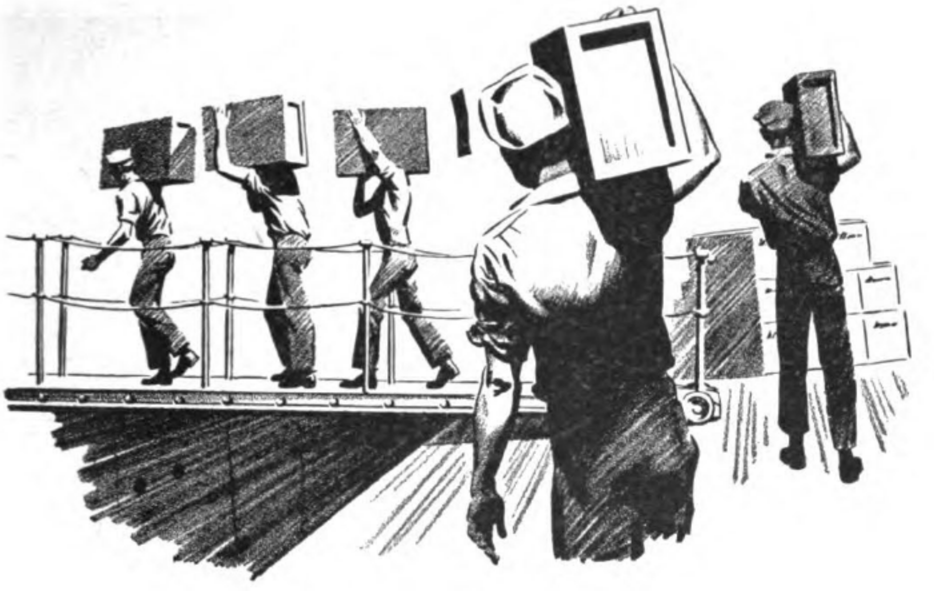
of the theoretical mechanical advantages of all the SIMPLE MACHINES which make it up.

CAMS are used to change circular motion into straight-line motion.

One of the gear systems you'll get to see frequently aboard ship is that on the ANCHOR WINCH. Figure 60 shows you one type in which you can readily see how the wheels go 'round. The driving gear *A* is turned by the winch engine or motor. This gear has 22 teeth, which mesh with the 88 teeth on the large wheel *B*. Thus, you know that the large wheel makes one revolution for every four revolutions of the driving gear *A*. You get a 4-to-1 theoretical mechanical advantage out of that pair. Secured to the same shaft with *B* is the small spur gear *C*, covered up here. The gear *C* has 30 teeth which mesh with the 90 teeth on the large gear *D*, also covered up. The advantage from *C* to *D* is 3 to 1. The sprocket wheel to the far left, on the same shaft with *D*, is called a WILDCAT. The anchor chain is drawn up over this. Every second link is caught and held by the protruding teeth of the wildcat. The over-all mechanical advantage of the winch is $4 \times 3$, or 12 to 1.

Figure 61 shows you an application of the RACK AND PINION as a steering mechanism. Turning the ship's wheel turns the small pinion *A*. This pinion causes the internal spur gear to turn. Notice that there is a large mechanical advantage in the arrangement.

Now you see that center pinion *P* turns. It meshes with the two vertical racks. When the wheel is turned full to the right, one rack moves downward and the other moves upward to the positions of the racks. Attached to the bottom of the racks are two hydraulic pistons which control the steering of the ship. You'll get some information on this hydraulic system in a later chapter.



## CHAPTER 7

# WORK

### WHAT'S WORK?

You know that machines help you to do work. But just WHAT IS WORK? Work doesn't mean simply applying a force. If that were so, you would have to consider that Big-Boy, busily applying his 220-pound force on the sea bag in figure 62, is doing work. But NO WORK is being done!

Work, in the mechanical sense of the term, is done when a RESISTANCE IS OVERCOME BY A FORCE ACTING THROUGH A MEASUREABLE DISTANCE. Now, if Big-Boy were to lift his 90-pound bag off the deck and put it on his bunk, he would be doing work. He would be OVERCOMING A RESISTANCE BY APPLYING A FORCE THROUGH A DISTANCE.

Notice that two factors are involved—FORCE and MOVEMENT THROUGH A DISTANCE. The force is normally measured in pounds, and the distance in FEET. WORK, therefore, is commonly measured in units called FOOT-POUNDS. You do one foot-pound of work when you lift a one-pound weight through a height of one foot. But—you also do ONE foot-pound of work when you apply ONE pound of force on any object through a distance of ONE foot. Writing this as a formula, it becomes—

$$\underset{\text{(foot-pounds)}}{\text{WORK}} = \underset{\text{(pounds)}}{\text{FORCE}} \times \underset{\text{(feet)}}{\text{DISTANCE}}$$

Thus, if the sailor lifts a 90-pound bag through a vertical distance of 5 feet, he will do—

$$\text{WORK} = 90 \times 5 = 450 \text{ ft.-lb.}$$

## A WORD TO THE WISE

There are two points concerning work that you should get straight right at the beginning.

First, in calculating the work done you measure the


Figure 62.—No work is being done.

ACTUAL RESISTANCE being overcome. This is not necessarily the weight of the object being moved. To make this clear, look at the job the bluejacket in figure 65 is doing. He is pulling a 900-pound load of supplies 200 feet along the dock. Does this mean that he is doing 900 times 200, or 180,000 foot-pounds of work? OF COURSE NOT. He isn't working against the PULL OF GRAVITY—or the total weight—of the load. He's pulling only against the ROLLING FRICTION of the truck, and that may be as little as 90 pounds. THAT is the resistance which is being overcome. Always be sure that you know WHAT RESISTANCE is being overcome by the effort, as well as the distance through which it is moved. The resistance in one case may be the WEIGHT of the

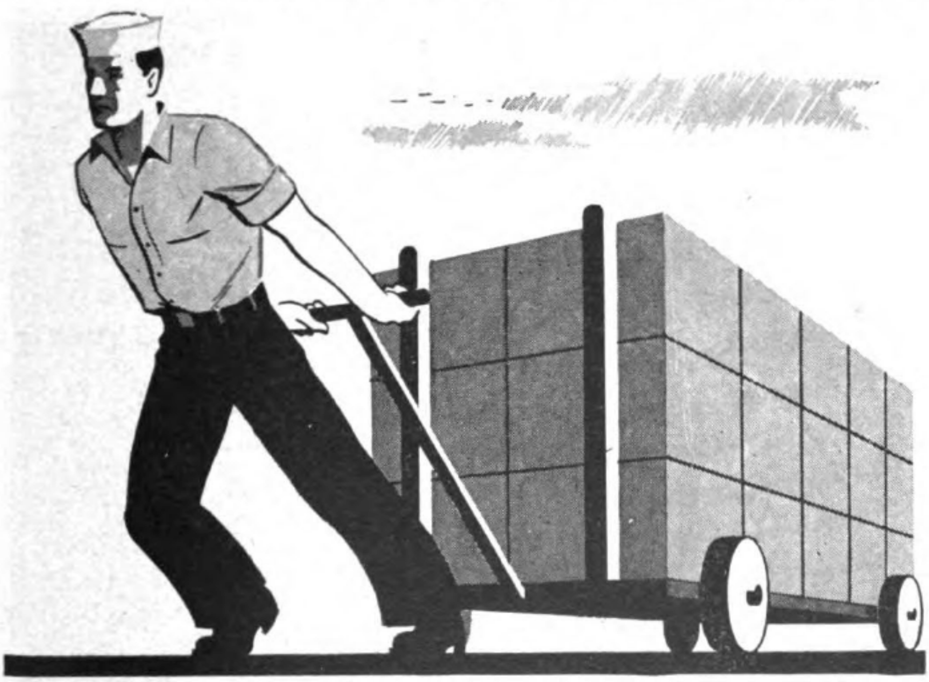


Figure 63.—Working against friction.

OBJECT; in another it may be the FRICTIONAL RESISTANCE of the object as it is dragged or rolled along the deck.

The SECOND point to hold in mind is that you have to MOVE the resistance to do any work on it. Look at Willie in figure 64. The poor guy has been holding that suitcase for the past 15 minutes waiting for the bus. His arm is getting tired; but according to the definition of WORK, he isn't doing any—because he isn't moving the suitcase. He is merely exerting a force against the pull of gravity on the bag. O. K., Willie, you can put it down now.

## WORKING WITH LEVERS

You already know about the mechanical advantage of a LEVER. Now consider it in terms of getting work done easily. Look at figure 65. The load weighs 300 pounds, and you want to lift it up onto a platform a foot above the deck. How much work must you do on it? Since 300 pounds must be raised one foot, 300 times 1, or 300 foot-pounds of work must


Figure 64.—No motion, no work.

be done. You can't make this weight any smaller by the use of any machine. However, if you use the eight-foot plank as shown, you can do that amount of work, by applying a SMALLER force through a LONGER distance. Notice that you have a mechanical advantage of 3, so that a 100-pound push DOWN on the end of the plank will RAISE the 300-pound crate. Through how long a distance will you have to exert that 100-pound push? Neglecting friction—and in this case you can safely do so—the work done ON the machine is equal to the work done BY the machine. Say it this way—

*Work put in=work put out.*

And since Work = force x distance, you can substitute "force times distance" on each side of the work equation. Thus—

$$F_1 \text{ times } S_1 = F_2 \text{ times } S_2$$

in which,

$F_1$ = effort applied, in pounds
$S_1$ = distance through which effort moves, in feet
$F_2$ = resistance overcome, in pounds
$S_2$ = distance resistance is moved, in feet

Now substitute the known values, and you obtain—

$$100 \text{ times } S_1 = 300 \text{ times } 1$$
$$S_1 = 3 \text{ feet}$$

The advantage of using the lever is not that it makes any less work for you, but that it allows you to

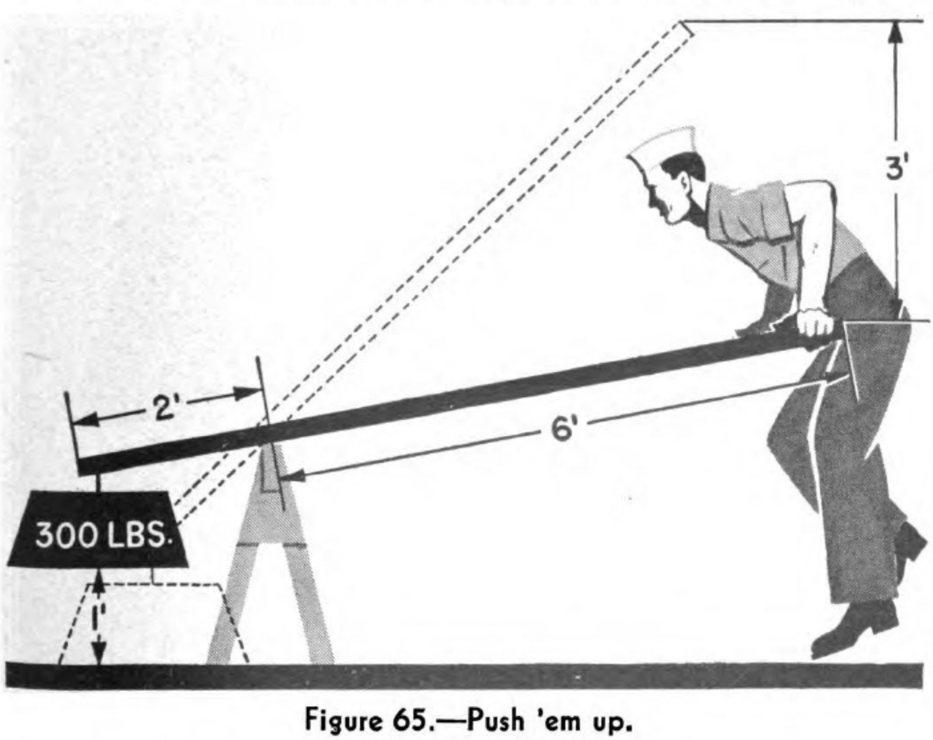



Figure 65.—Push 'em up.

do the job with the force at your command. You'd probably have some difficulty lifting 300 pounds directly upward without a machine to help you!

## WORK DONE WITH BLOCKS

A block and tackle also makes work easier. But like any other machine, it can't decrease the total AMOUNT OF WORK to be done. With a rig like the one shown in figure 66, the bluejacket has a mechanical advantage of 5, neglecting friction. Notice that five parts of the rope go to and from the movable block.

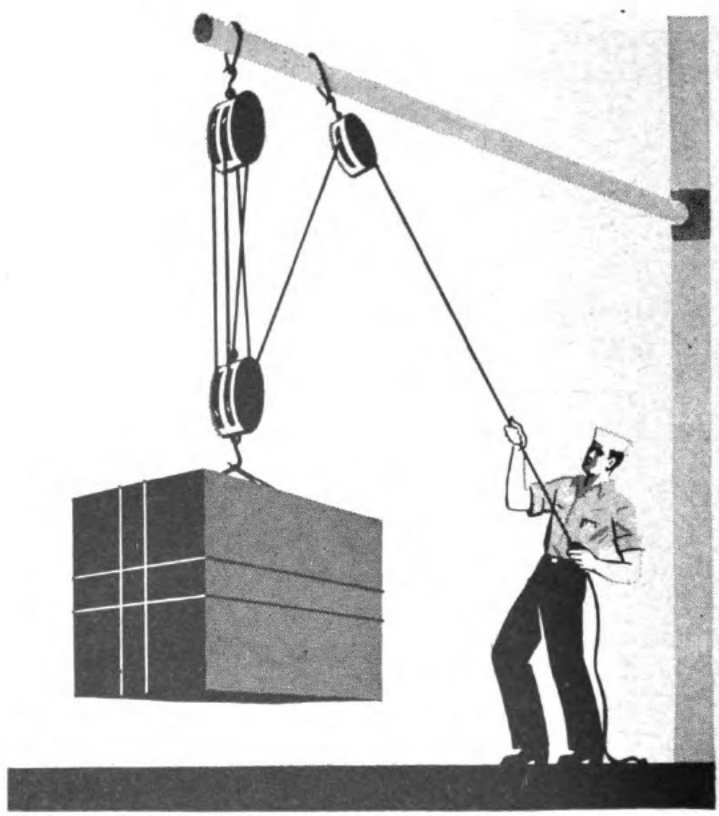


Figure 66.—A block and tackle makes work easier.

To raise the 600-pound load 20 feet, he needs to exert a pull of only $\frac{1}{5}$ of 600—or 120 pounds. But—he is going to have to pull MORE THAN 20 FEET OF ROPE through his hands in order to do this. Use the formula again to figure why this is so—

*Work input=work output*

$$F_1 \times S_1 = F_2 \times S_2$$

And by substituting the known values—

$$120 \times S = 600 \times 20$$

$$S_1 = 100 \text{ feet.}$$

This means that he has to pull 100 feet of rope through his hands in order to raise the load 20 feet. Again, the advantage lies in the fact that a relatively SMALL FORCE operating through a LARGE DISTANCE can move a BIG LOAD through a SMALL DISTANCE.

## THE JACK AT WORK

The sailor busy with the big piece of machinery in figure 67 has his work cut out for him. He is

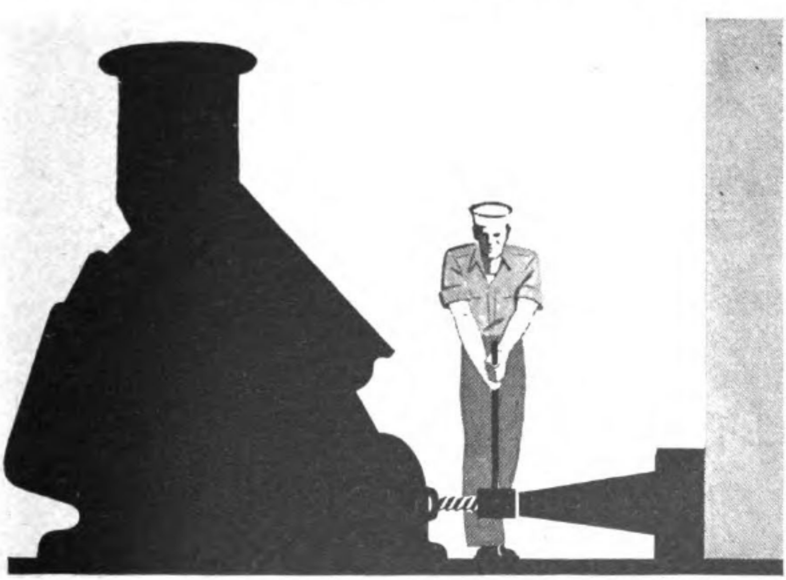


Figure 67.—A big push.

trying to seat the machine square on its foundations. The rear end must be shoved over one-half foot against a frictional resistance of 1,500 pounds. The amount of work to be done is $1{,}500 \times \frac{1}{2}$, or 750 foot-pounds. He will have to do at least this much work on the jack he is using. If the jack has a 2½-foot handle—$R = 2\frac{1}{2}$ ft.—and the pitch of the jack screw is ¼ inch, he can do the job with little effort. Neglecting friction, you can figure it out this way—

$$\textit{Work input} = \textit{work output}$$

$$F_1 \times S_1 = F_2 \times S_2$$

In which

$F_1$ = force in pounds applied on the handle;
$S_1$ = distance, in feet, that the end of the handle travels in one revolution;
$F_2$ = resistance to be overcome;
$S_2$ = distance in feet that head of jack is advanced by one revolution of the screw. Or, the PITCH of the screw.

And, by substitution,

$$F_1 \times 2R = 1500 \times \tfrac{1}{48}, \text{ since } \tfrac{1}{4}'' = \tfrac{1}{48} \text{ of a foot}$$

$$F_1 \times 2 \times 2\tfrac{1}{2} = 1500 \times \tfrac{1}{48}$$

$$F_1 = 2 \text{ pounds.}$$

The jack makes it theoretically possible for the sailor to exert a 1,500-pound push with a 2-pound effort, but look at the distance through which he must apply that effort. One complete turn of the handle represents a distance of 15.7 feet. That 15.7-foot rotation advances the piece of machinery only ¼th of an inch—or ¹⁄₄₈th of a foot. Force is gained at the expense of distance.

## FRICTION

You are going to push a 400-pound crate up a 12-foot plank, the upper end of which is 3 feet higher than the lower end. You figure out that a 100-pound push will do the job, since the height the crate is to be raised is ONE-FOURTH of the distance through which you are exerting your push. The theoretical mechanical advantage is 4. And then you push 100 pounds worth. Nothing happens! You've forgotten that there is FRICTION between the surface of the crate and the surface of the plank.

This friction acts as a resistance to the movement of the crate—and you must overcome this resistance to move the crate. In fact, you might have to push as much as 150 pounds to move it. Fifty pounds would be used to overcome the FRICTIONAL RESISTANCE, and the remaining 100 pounds would be the useful push that would move the crate up the plank.

FRICTION IS THE RESISTANCE THAT ONE SURFACE OFFERS TO ITS MOVEMENT OVER ANOTHER SURFACE. The amount of friction depends upon the NATURE of the

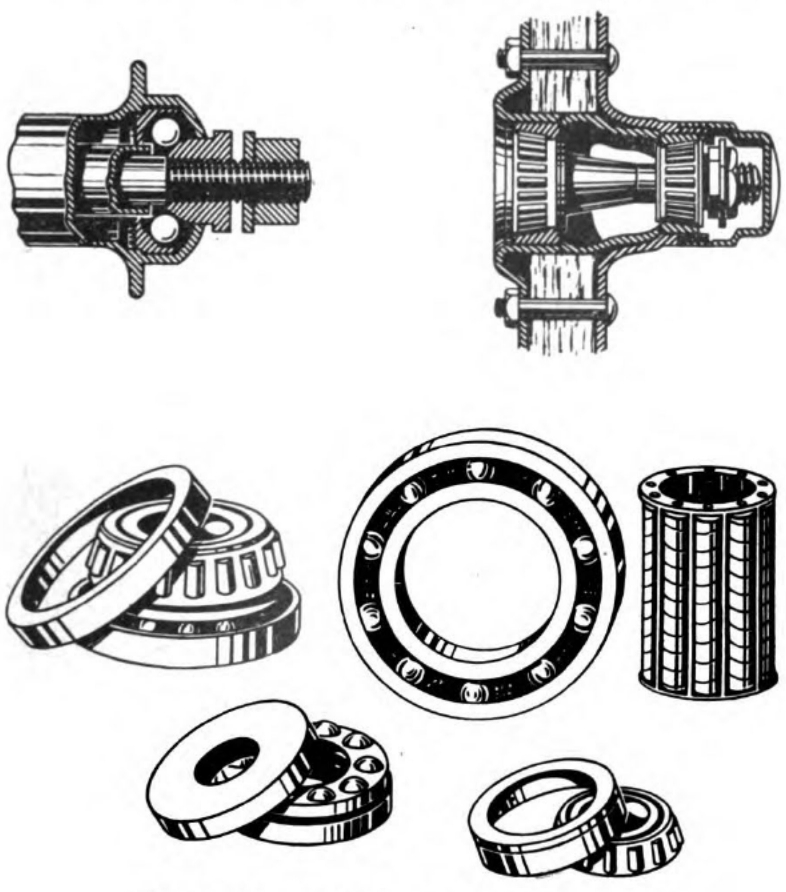


Figure 68.—These reduce friction.

two surfaces, and the FORCES which hold them together.

In many instances friction is useful to you. Friction helps you hold back the crate from sliding down the inclined ramp. The cinders you throw under the wheels of your car when it's slipping on an icy pavement increase the friction. You wear rubber-soled shoes in the gym to keep from slipping. And locomotives carry a supply of sand which can be dropped on the tracks in front of the driving wheels to INCREASE THE FRICTION between the wheels and the track. Nails hold structures together because of the friction between the nails and the lumber.

When you are trying to stop or slow-up an object in motion, when you want traction, and when you want to PREVENT motion from taking place, you make friction work for you. But when you want a machine to run smoothly and at high efficiency, you eliminate as much friction as possible by oiling and greasing bearings, and honing and smoothing rubbing surfaces.

Wherever you apply force to cause motion, friction makes the ACTUAL mechanical advantage fall short of the THEORETICAL mechanical advantage. Because of friction, you have to make a greater effort to overcome the resistance which you want to move. If you place a marble and a lump of sugar on a table and give each an equal push, the marble will move farther. This is because ROLLING FRICTION is always less than SLIDING FRICTION. You take advantage of this fact whenever you use ball bearings or roller bearings. See figure 68.

Remember that ROLLING FRICTION is always LESS than SLIDING ERICTION. The Navy takes advantage of that fact. Look at figure 69. This roller chock not only cuts down the wear and tear on lines and cables which are run through it, but—by reducing friction—also reduces the load the anchor winch has to work against.

The roller bitt in figure 70 is ANOTHER example of how you can cut down the wear and tear on lines or cable and also reduce your frictional loss.

When it is necessary to have one surface move over another, you can decrease the friction by the use of


Figure 69.—It saves wear and tear.

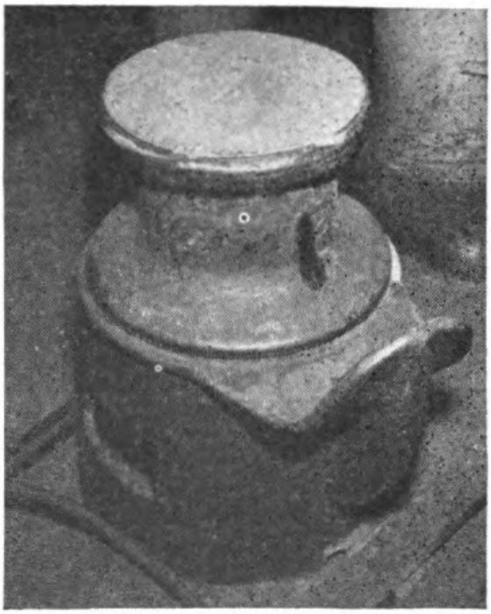


Figure 70.—Roller bitt saves lines.

LUBRICANTS, such as oil, grease, or soap. You will use lubricants on flat surfaces, gun slides for example, as well as on ball and roller bearings, to further reduce the frictional resistance and to cut down the wear.

## BEARINGS

You know from experience that the friction between a rubber sole and a wood floor is greater than

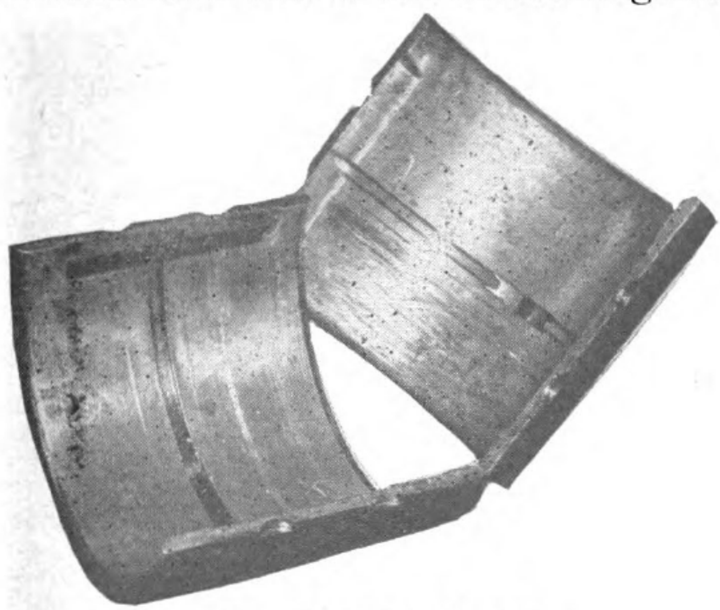


Figure 71.—These are big ones.

the friction between a leather sole and the floor. Frictional force depends IN PART upon the nature of the materials from which the two contacting surfaces are made. Steel rubbing against steel makes a poor bearing surface because of high friction losses. Therefore, softer BEARING METALS are commonly used as one of the two bearing surfaces. If a rotating shaft is made of steel, the surface on which it turns will be lined with a bearing-metal bushing. Figure 71 shows you a pair of these bearing inserts. Figure 72 shows you how the inserts fit into the bearings. The bearing metal, plus proper lubrication cuts down the sliding friction to a minimum.

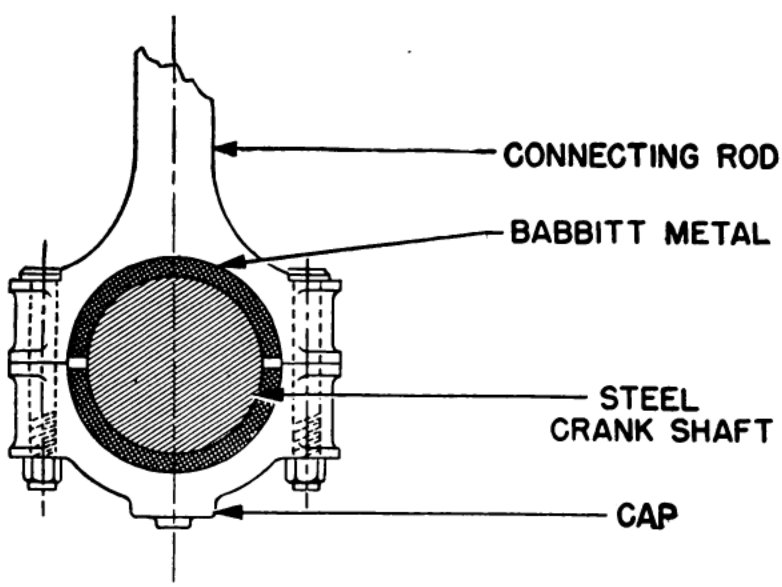



Figure 72.—Connecting-rod bearings.

On the other hand, where roller or ball bearings are used, you find steel bearing on steel.

Don't forget that in a lot of situations friction is mighty helpful, however. Many a bluejacket has found out about this the hard way—on a wet, slippery deck. On some of our ships you'll find that a rough-grained deck covering is used. Here you have friction working FOR you. It helps you to keep your footing.

Up to this point you have been neglecting the effect of FRICTION on machines. This makes it easier to explain machine operation, but you know from practical experience that friction is involved every time two surfaces move against one another. And the work used in overcoming the frictional resistance does not appear in the work output. Since this is so, it's obvious that you have to put more work into a machine than you get out of it. In other words, no machine is 100 percent efficient.

Take the jack in figure 43, for example. The chances are good that a 2-pound force exerted on the handle wouldn't do the job at all. More likely a pull of at least 10 pounds would be required. This indicates that only 2 out of the 10 pounds, or 20 percent of the effort is usefully employed to do the job. The remaining 8 pounds of effort were consumed in OVERCOMING THE FRICTION in the jack. Thus, the jack has an EFFICIENCY of only 20 percent. Most jacks are inefficient, but even with this inefficiency, it is possible to deliver a hugh push with a small amount of effort.

A simple way to calculate the efficiency of a machine is to divide the output by the input—

$$\text{Efficiency}=\frac{\text{Output}}{\text{Input}}$$

Now go back to the block-and-tackle problem illustrated in figure 66. It's likely that instead of being able to lift the load with a 120-pound pull, the bluejacket would perhaps have to use a 160-pound pull through the 100 feet. You can calculate the efficiency of the rig by the following method—

$$\text{Efficiency}=\frac{\text{output}}{\text{input}}=\frac{F_2\times S_2}{F_1\times S_1}$$

and, by substitution, $=\frac{600\times 20}{160\times 100}=0.75$ or 75 percent.

Theoretically, with the mechanical advantage of twelve developed by the cable winch back in figure 57, you should be able to lift a 600-pound load with a 50-pound push on the handle. If the machine has an efficiency of 60 percent, how big a push would you actually have to apply? Actually, $50 \div 0.60 = 83.3$ pounds. You can check this yourself in the following manner—

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{F_2 \times S_2}{F_1 \times S_1}$$

One revolution of the drum would raise the 600-pound load a distance $S_2$ of $2\pi r$ or 7.85 feet. To make the drum revolve ONCE, the pinion gear must be rotated SIX times by the handle; and the handle must be turned through a distance $S_1$ of $6 \times 2\pi R$, or 94.2 feet. Then, by substitution—

$$0.60 = \frac{600 \times 7.85}{F_1 \times 94.2}$$

and

$$F_1 = \frac{600 \times 7.85}{94.2 \times 0.60} = 83.3 \text{ pounds.}$$

Because this machine is only 60-percent efficient, you have to put 94.2×83.3, or 7,847 foot-pounds of work into it in order to get 4,710 foot-pounds of work out of it. The difference—7,847 − 4,710 = 3,137 foot-pounds—is used to OVERCOME FRICTION within the machine.

## THINK IT OVER

Here are some of the important points you should remember about friction, work, and efficiency—

You do WORK when you apply a force against a resistance and MOVE the resistance.

Since FORCE—measured in pounds—and DISTANCE—measured in feet—are involved, WORK is measured in FOOT-POUNDS. One foot-pound of work is the result of a one-pound force, acting against a resistance through a distance of one foot.

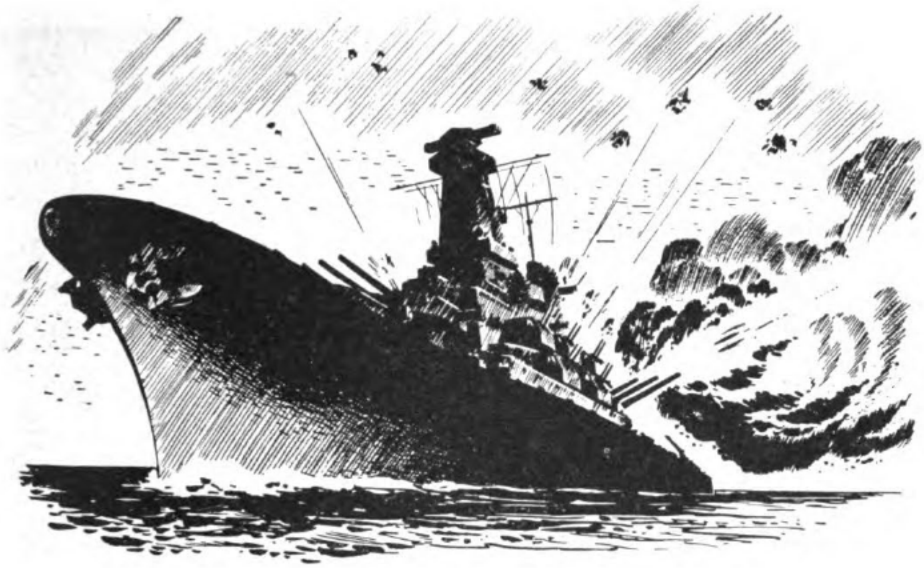
Machines help you to do work by making it possible to move a large resistance through a small distance by the application of a small force through a large distance.

Since friction is present in all machines, more work must be done on the machine than the machine actually does on the load.

The EFFICIENCY of any machine can be found by dividing the OUTPUT by the INPUT.

The resistance that one surface offers to movement over a second surface is called FRICTION.

FRICTION between two surfaces depends upon the nature of the material and the magnitude of the forces pushing them together.



## CHAPTER 8

# POWER

### WORK AGAINST TIME

It's all very well to talk about how much work a man can do, but the pay-off is how long it takes him to do it. Look at "Lightning" in figure 73. He has lugged 3 tons of bricks up to the second deck of the new barracks. However, it has taken him three 10-hour days—1,800 minutes—to do the job. In raising the 6,000 pounds 15 feet he did 90,000 foot-pounds of work. Remember—FORCE $\times$ DISTANCE = WORK. Since it took him 1,800 minutes, he has been working at the RATE OF $90{,}000 \div 1{,}800$, or 50 foot-pounds of work PER MINUTE.

That's POWER—the RATE OF DOING WORK. Thus, power always includes the TIME ELEMENT. Doubtless you could do the same amount of work in one 10-hour day, or 600 minutes—which would mean that you would work at the rate of $90{,}000 \div 600 = 150$ foot-pounds per minute. You then would have a power value THREE TIMES as great as that of "Lightning."

By formula—

$$\text{Power} = \frac{\text{Work, in ft.-lb.}}{\text{Time, in minutes}}$$

## HORSEPOWER

You measure force in pounds; distance in feet; work in foot-pounds. What is the common unit used for measuring POWER? The HORSEPOWER. If you

Figure 73.—Get a horse.

want to tell someone how powerful an engine is, you COULD say that it is so many times more powerful than a man, or an ox, or a horse. But what a man, and whose ox or horse? James Watt, the fellow who invented the steam engine, compared his early models with the horse. By experiment, he found that an average horse could lift a 330-pound load straight up through a distance of 100 feet in one minute. Figure 74 shows you the type of rig he used to find this out. By agreement among scientists, that figure of 33,000 FOOT-POUNDS OF WORK DONE IN ONE MINUTE has been accepted as the standard unit of power, and it is called a HORSEPOWER—hp.

Since there are 60 seconds in a minute, one horsepower is also equal to $\frac{33,000}{60}=550$ foot-pounds per second. By formula—

$$\text{Horsepower}=\frac{\text{Power (in ft.-lb. per min.)}}{33,000}$$

## CALCULATING POWER

It isn't difficult to figure how much power is needed to do a certain job in a given length of time,

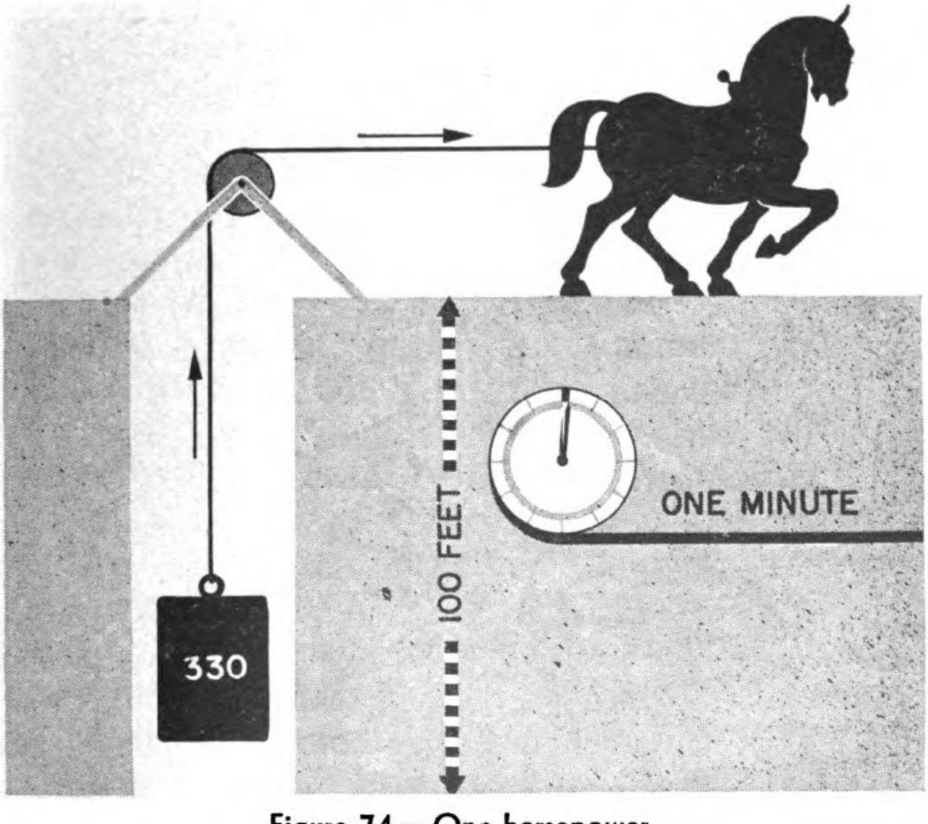



Figure 74.—One horsepower.

nor to predict what size engine or motor is needed to do it. Suppose an anchor winch must raise a 6,600-pound anchor through 120 feet in 2 minutes. What must be the theoretical horsepower rating of the motor on the winch?

The first thing to do is to find the RATE at which the work must be done. You see the formula—

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{\text{force} \times \text{distance}}{\text{time}}$$

Substitute the known values in the formula, and you get—

$$\text{Power} = \frac{6{,}600 \times 120}{2} = 396{,}000 \text{ ft.-lb./min.}$$

So far, you know that the winch must work at a rate of 396,000 ft.-lb./min. To change this rate to horsepower, you divide by the rate at which the average horse can work—33,000 ft.-lb./min.

$$\text{Horsepower} = \frac{\text{Power (ft.-lb./min.)}}{33{,}000} = \frac{396{,}000}{33{,}000} = 12 \text{ hp.}$$

THEORETICALLY, the winch would have to be able to work at a RATE of 12 HORSEPOWER in order to get the anchor aweigh in 2 minutes. Of course, you've left out ALL FRICTION in this problem, so the winch motor would actually have to be larger than 12 hp.

Planes are raised from the hangar deck to the flight deck of a carrier on an elevator. Some place along the line, an engineer had to figure out how powerful the motor had to be in order to raise the elevator. It's not too tough when you know how. Allow a weight of 10 tons for the elevator, and 5 tons for the plane. Suppose that you want to raise the elevator and plane 25 feet in 10 seconds. And that the over-all efficiency of the elevator mechanism is 70 percent. With that information you can figure what the delivery horsepower of the motor must be. Set up the formulas—

$$\text{Power} = \frac{\text{force} \times \text{distance}}{\text{time}}$$

$$\text{hp} = \frac{\text{power}}{33{,}000}$$

Substitute the known value in their proper places, and you have—

$$\text{power} = \frac{30{,}000 \times 25 \text{ ft.}}{10/60 \text{ minute}} = 4{,}500{,}000 \text{ ft. lb./min.}$$

$$\text{hp} = \frac{4{,}500{,}000}{33{,}000} = 136.4 \text{ hp.}$$

So, 136.4 horsepower would be needed if the engine had 100 percent over-all efficiency. You want to use 70 percent efficiency, so you use the formula—

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$\text{Input} = \frac{136.4}{0.70} = 194.8 \text{ hp.}$$

This is the rate at which the engine must be able to work. To be on the safe side, you'd probably select a 200-horsepower auxiliary to do the job.

## FIGURING THE HORSEPOWER RATING OF A MOTOR

You have probably seen the horsepower rating plates on electric motors. A number of methods may be used to determine this rating. One way that the rating of a motor or a steam or gas engine can be found is by the use of the PRONY BRAKE. Figure 75 shows you the Prony brake setup. A pulley wheel is fixed to the shaft of the motor, and a leather belt is held firmly against the pulley. Attached to the two ends of the belt are spring scales. When the motor is standing still, each scale reads the same—say 15 pounds. When the pulley turns in a clockwise direction, the friction between the belt and the pulley makes the belt TRY to move with the pulley. Therefore, pull on scale *A* will be greater, and the pull on scale *B* will be less than 15 pounds.

Suppose that scale *A* reads 25 pounds, and scale *B* reads 5 pounds. That tells you that the drag, or the force against which the motor is working, is $25-5=20$ pounds. In this case the normal speed of the motor is 1,800 rpm (revolutions per minute) and the diameter of the pulley is one foot.

The number of revolutions can be found by holding the revolution counter C against the end of the shaft for one minute. This counter will record the number of turns the shaft makes per minute. The distance *D* which any point on the pulley travels in

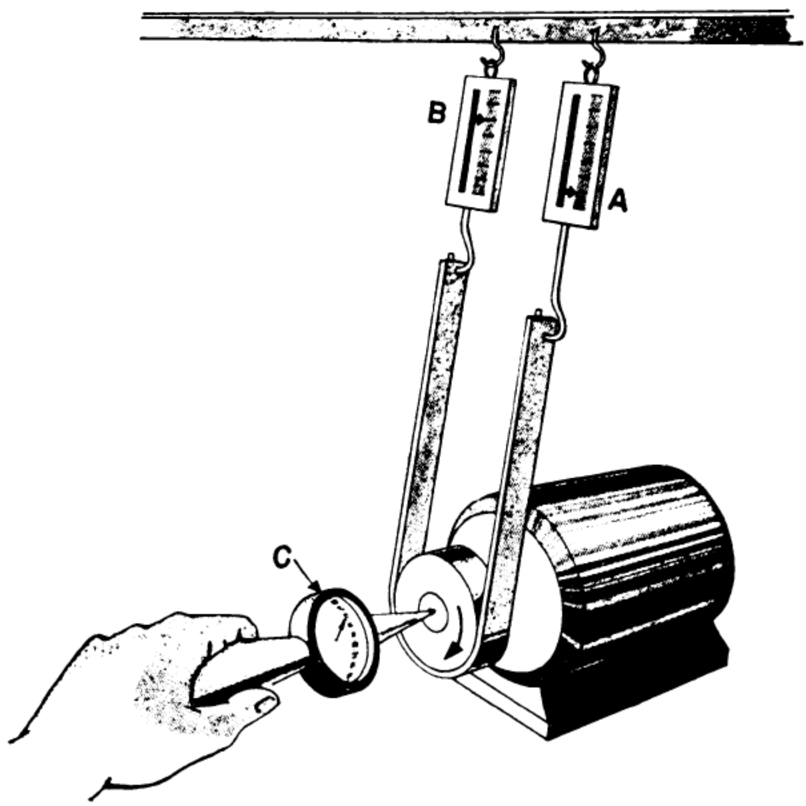



Figure 75.—A Prony brake.

one minute is equal to the circumference of the pulley times the number of revolutions—$3.14 \times 1 \times 1{,}800 = 5{,}652$ ft.

You know that the motor is exerting a force of 20 pounds through that distance. The WORK done in ONE MINUTE is equal to the FORCE times the DISTANCE, or WORK$=F \times D = 20 \times 5{,}652 = 113{,}040$ ft.-lb./min. Change this to horsepower—

$$\frac{113{,}040}{33{,}000} = 3.43 \text{ hp.}$$

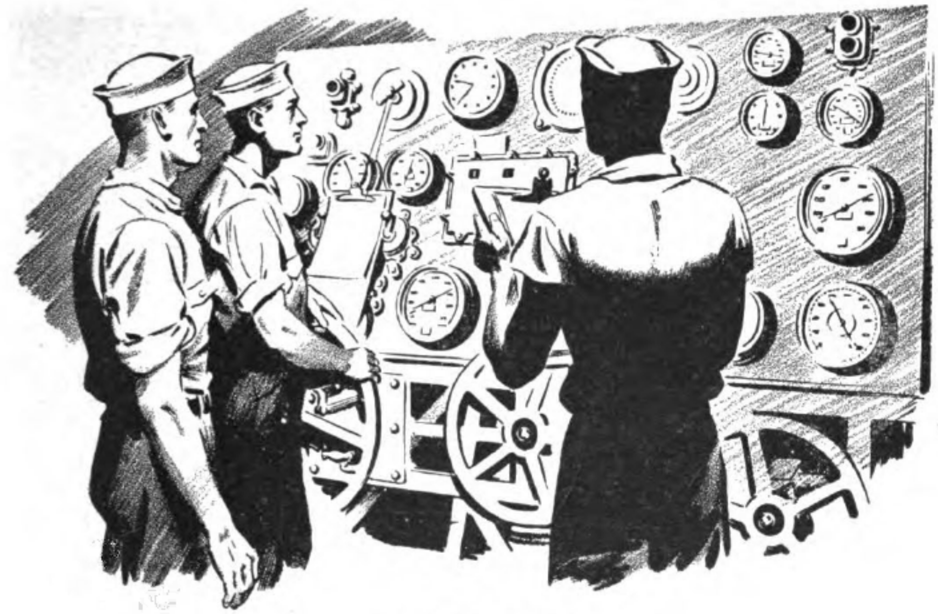
Here are a few ratings for motors or engines with which you are familiar—an electric mixer has a $\frac{1}{16}$-hp. motor; a washing machine a $\frac{1}{4}$-hp. motor; the engine in a Corsair F4U develops around 2,000 hp, and a battleship is driven by 200,000-hp. engines.

### SHORT AND SWEET

There are two important points for you to remember about POWER—

POWER is the RATE at which WORK is done.

The unit in which power is measured is the HORSEPOWER, which is equivalent to working at a rate of 33,000 ft.-lb. per min., or 550 ft.-lb. per sec.



CHAPTER 9

# FORCE AND PRESSURE

## FORCES SURROUND YOU

By this time you should have a pretty good idea of what a FORCE is. A FORCE is a PUSH or a PULL exerted on—or by—an object. You apply a force on a machine, and the machine in turn transmits a force to the load. Men and machines, however, are not the only things that can exert forces. If you've been out in a sailboat you know that the wind can exert a force. Further, you don't have to get knocked on your ear more than a couple of times by the waves to get the idea that water, too, can exert a force. As a matter of fact, from reveille to taps you are almost constantly either exerting forces or resisting them. That's the reason you are pooped when you hit the sack.

## MEASURING FORCES

You've had a lot of experience in measuring forces. You can estimate or "guess" the weight of a package you're going to mail by "hefting" it. Or you can put it on a scale to find its weight accurately. WEIGHT is a common term that tells you how much force or pull gravity is exerting on the object.

You can readily measure force with a spring scale. An Englishman named Hooke discovered that if you hang a 1-pound weight on a spring, the spring stretches a certain distance. A 2-pound weight will extend the spring just twice as far, and 3 pounds will lengthen it three times as far as the 1-pound weight did. Right there is the makings of the spring scale. All you need to do is attach a pointer to the spring,

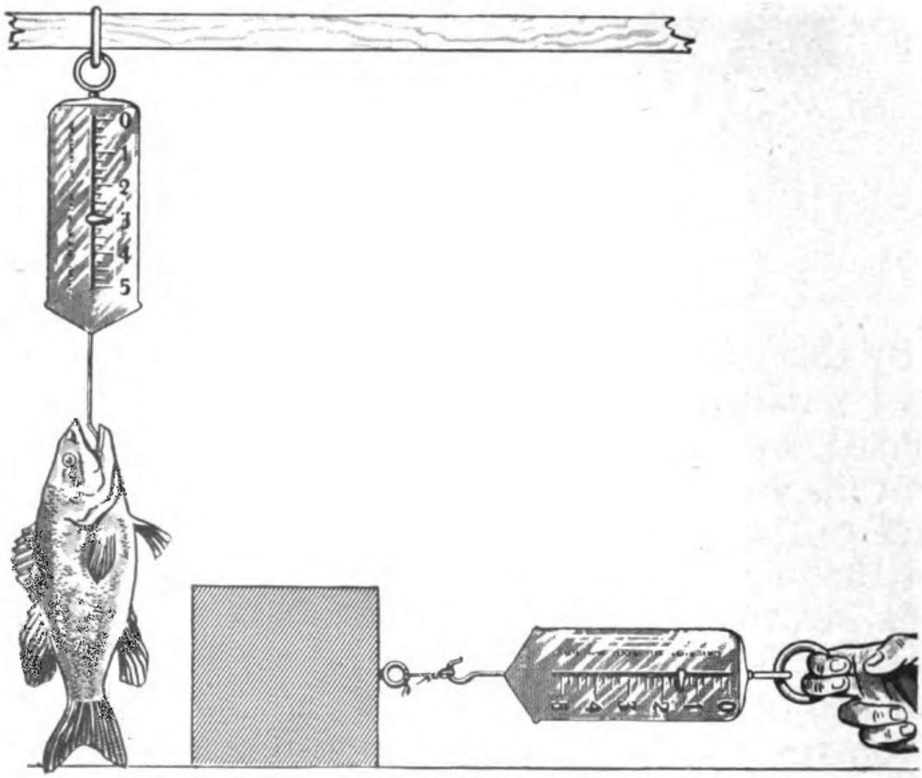


Figure 76.—You can measure force with a scale.

put a face on the scale, and mark on the face the positions of the pointer for various loads in pounds or ounces.

This type of scale can be used to measure the pull of gravity—the weight—of an object, or the force of a pull exerted against friction, as shown in Figure 76. Unfortunately, springs get tired, just as you do. When they get old, they don't always snap back to the original position. Hence an old spring or an overloaded spring will give inaccurate readings.

## HONEST WEIGHT—NO SPRINGS

Because springs do get tired, other types of force-measuring devices are made. You've seen the sign, "*Honest Weight—No Springs*", on the butcher-shop scales. Scales of this type are shown in Figure 76. They are applications of FIRST-CLASS LEVERS.

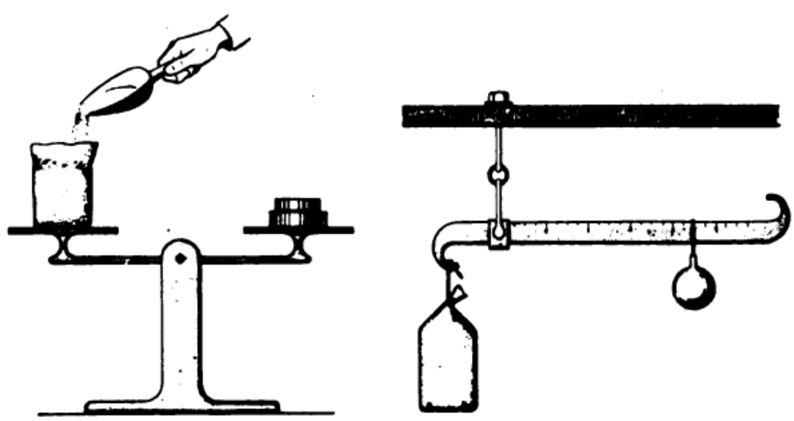



Figure 77.—Balances.

The one shown in figure 76a is the simplest type. Since the distance from the fulcrum to the center of each platform is equal, the scale is balanced when equal weights are placed on the platforms. With your knowledge of levers, you will be able to figure out how the STEEL YARD shown in Figure 76b operates.

## PRESSURE

Have you ever tried to walk on crusted snow that would break through when you put your weight on it? But you could walk on the same snow if you put on snowshoes. Further, you know that snow-shoes do not reduce your weight—they merely distribute it over a larger area. In doing this, they reduce the PRESSURE. Figure out how that works. If you weigh 160 pounds, that weight, or force, is more or less evenly distributed by the soles of your shoes. The area of the soles of an average man's shoes is roughly 60 square inches. Each one of those square inches has to carry $160 \div 60 = 2.6$ pounds of your weight. Since 2.6 pounds per square inch is too much for the snow crust, you break through.

When you put on the snowshoes, you distribute your weight over an area of approximately 900 sq. in.—depending, of course, on the size of the snowshoes. Now the force on each one of those square inches is equal to only $160 \div 900 = 0.18$ pound. The pressure on the snow has been decreased, and the snow can easily support you.

PRESSURE IS FORCE PER UNIT AREA—and is measured, for example, in pounds per square inch—"psi." With snowshoes on, you exert a pressure of 0.18 psi. To calculate PRESSURE, DIVIDE the FORCE by the AREA over which the force is applied. The formula is—

$$\text{Pressure, in psi} = \frac{\text{Force, in lb.}}{\text{Area, in sq. in.}}$$

Or

$$P = \frac{F}{A}$$

To get this idea, follow this problem. A tank for holding fresh water aboard a ship is 10 feet long, 6 feet wide, and 4 feet deep. It holds, therefore, $10 \times 6 \times 4$, or 240 cubic feet of water. Each cubic foot of water weighs about 62.5 pounds. The total FORCE tending to push the bottom out of the tank is equal to the weight of the water—$240 \times 62.5$, or 15,000 lb. What is the PRESSURE on the bottom? Since the weight is evenly distributed on the bottom, you apply the formula $P = \frac{F}{A}$ and substitute the proper values for $F$ and $A$. In this case, $F = 15{,}000$ lb. and the area of the bottom in square inches is $10 \times 6 \times 144$, since 144 sq. in. = 1 sq. ft.

$$P=\frac{15{,}000}{10\times 6\times 144}=1.74 \text{ psi}$$

Now work out the idea in reverse. You live at the bottom of the great sea of air which surrounds the earth. Because the air has weight—gravity pulls on the air, too—the air exerts a force on every object which it surrounds. Near sea level that force on an area of 1 square inch is roughly 15

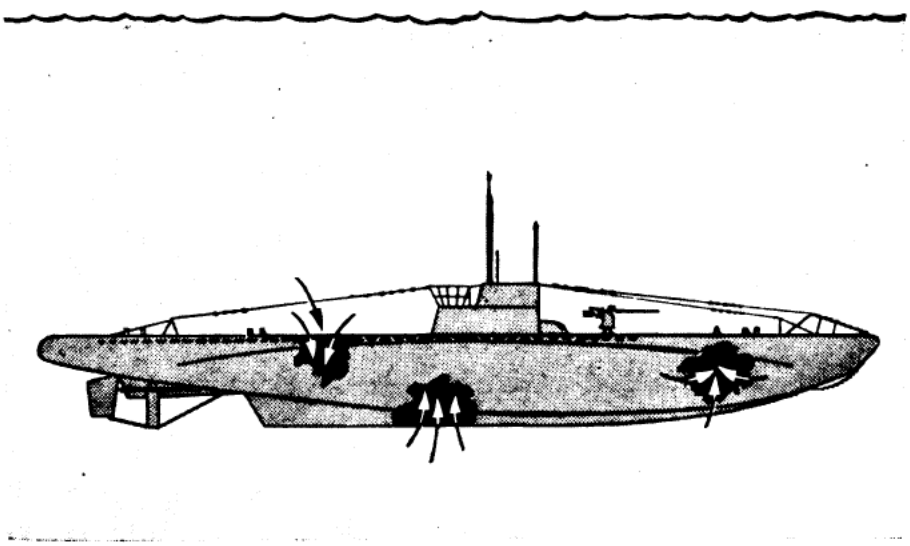


Figure 78.—Fluids exert pressure in all directions.

pounds. Thus, the air-pressure at sea level is about 15 psi. The pressure gets less and less as you go up to higher altitudes.

With your finger, mark out an area of one square foot on your chest. What is the total force which tends to push in your chest? Again use the formula $P=\frac{F}{A}$. Now substitute 15 psi for $P$, and for $A$ use 144 sq. in. Then $F=144\times 15$, or 2,160 lb. The force on your chest is 2,160 lb. per square foot—more than a ton pushing against an area of 1 sq. ft. If there were no air inside your chest to push outward with the same pressure, you'd be squashed flatter than a bride's biscuit.

Fluids— which include both liquids and gases— exert PRESSURE. A fluid at rest exerts equal pressure in all directions. Figure 78 shows that. Whether the hole is in the top, the bottom, or in one of the sides of a submarine, the water pushes in through the hole.

In many jobs aboard ship, it is necessary to know the pressure exerted by gas or a liquid. For example, it is important at all times to know the steam pressure inside of a boiler. One device to measure pressure is the BOURDON GAGE, shown at left in figure 79. Its

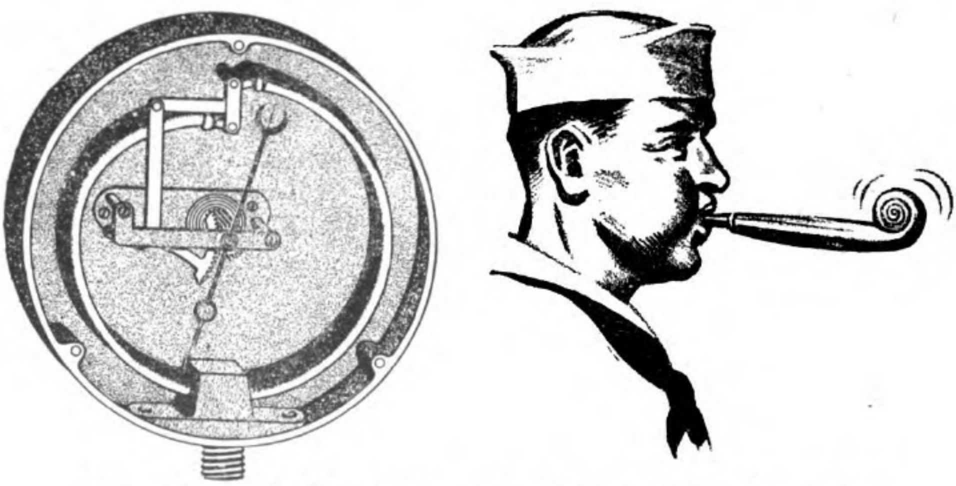


**Figure 79.—The Bourdon gage and its principle of operation.**

working principle is the same as that of those snake-like paper tubes which you get at a New Year's party. They straighten out when you blow into them. One of these gadgets is illustrated just to refresh your memory.

In the Bourdon gage there is a thin-walled metal tube, somewhat flattened, and bent into the form of a *C*. Attached to its free end is a lever system which magnifies any motion of the free end of the tube. The fixed end of the gage ends in a fitting which is threaded into the boiler system so that the pressure in the boiler will be transmitted to the tube. Like the paper "snake," the metal tube tends to straighten out when the pressure inside it is increased. As the tube straightens, the pointer is made to move around the dial. The pressure, in psi, may be read directly on the dial.

Air pressure and pressures of steam and other GASES are generally measured in POUNDS PER SQUARE INCH. For convenience, however, the pressure exerted by water is commonly measured in POUNDS PER SQUARE FOOT. You'll find more about this in Chapter 10.

## THE BAROMETER

To the average man, the chief importance of weather is as an introduction to general conversation.

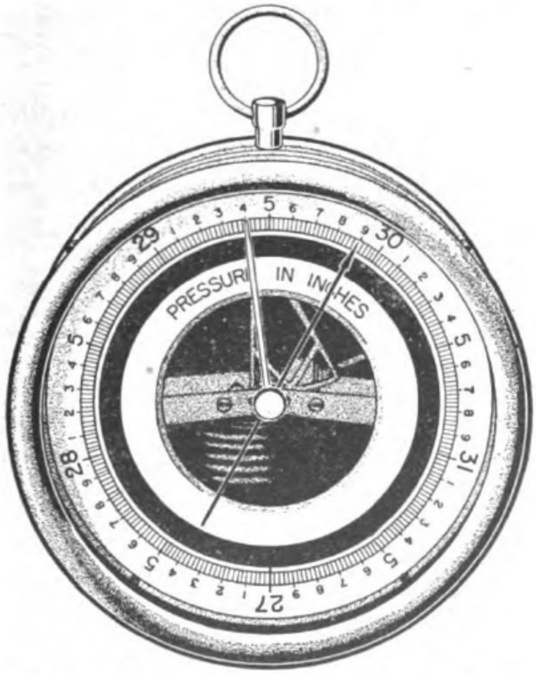



Figure 80.—An aneroid barometer.

But at sea and in the air, advance knowledge of what the weather will do is a matter of great concern to all hands. Operations are planned or cancelled on the basis of weather predictions. Accurate weather forecasts are made only after a great deal of information has been collected by many observers located over a wide area.

One of the instruments used in gathering weather data is the BAROMETER. Remember, the air is pressing on you all the time. So-called NORMAL atmospheric pressure is 14.7 psi. But as the weather changes, the air pressure may be greater or less than normal. If the air pressure is LOW in the area where you are, you know that air from one or more of the surrounding high-pressure areas is going to move in toward you. Moving air—or wind—is one of the most important factors in weather changes. In general, if you're in a LOW-PRESSURE area you may expect wind, rain, and storms. A HIGH-PRESSURE area generally enjoys clear weather. The barometer can tell you the air pressure in your locality, and give you a rough idea of what kind of weather may be expected.

The ANEROID BAROMETER shown in figure 80 is an instrument which measures air pressure. It contains a thin-walled metal box from which most of the air has been pumped. A pointer is mechanically connected to the box by a lever system. If the pressure of the atmosphere increases, it tends to squeeze in the sides of the box. This squeeze causes the pointer to move towards the high-pressure end of the scale. If the pressure decreases, the sides of the box expand outward. This causes the pointer to move toward the low-pressure end of the dial.

Notice that the numbers on the dial run from 28 to 31. To understand why these particular numbers are used, you have to understand the operation of the MERCURIAL BAROMETER. You see one of these in figure 81. It consists of a glass tube partly filled with mercury. The upper end is closed. There is a vacuum above the mercury in the tube, and the lower end of the tube is submerged in a pool of mercury in an open cup. The atmosphere presses down on the mercury in the cup, and tends to push the mercury up in the tube. The greater the air pressure, the higher the column of mercury rises. At sea level, the normal pressure is 14.7 psi, and the height of the mercury in the tube is 30 inches. As the air pressure increases or decreases from day to day, the

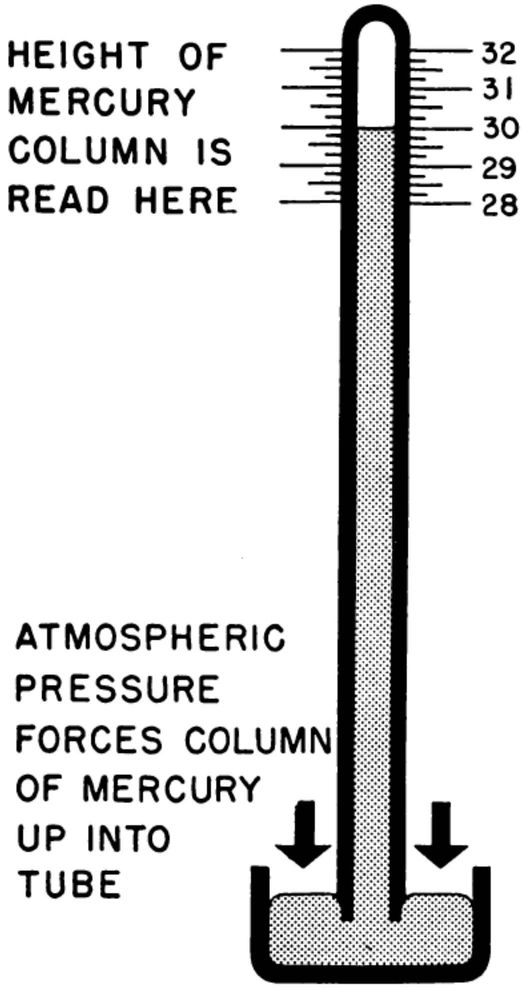



Figure 81.—A mercurial barometer.

height of the mercury rises or falls. A mercury barometer aboard ship is usually mounted in gimbals to keep it in a vertical position despite the rolling and pitching of the ship.

## MEASURING NEXT TO NOTHING

Pressures that you read on dials are usually RELATIVE. That is, they are either greater or less than normal. But REMEMBER—the gage of an ANEROID BAROMETER always reads ABSOLUTE PRESSURES, NOT RELATIVE. When the pressure exerted by any gas is less than 14.7 psi, you have what's called a PARTIAL VACUUM. The condensers on steam turbines, for instance, are operated at pressure well below 14.7 psi. Steam under very high pressure is run into the

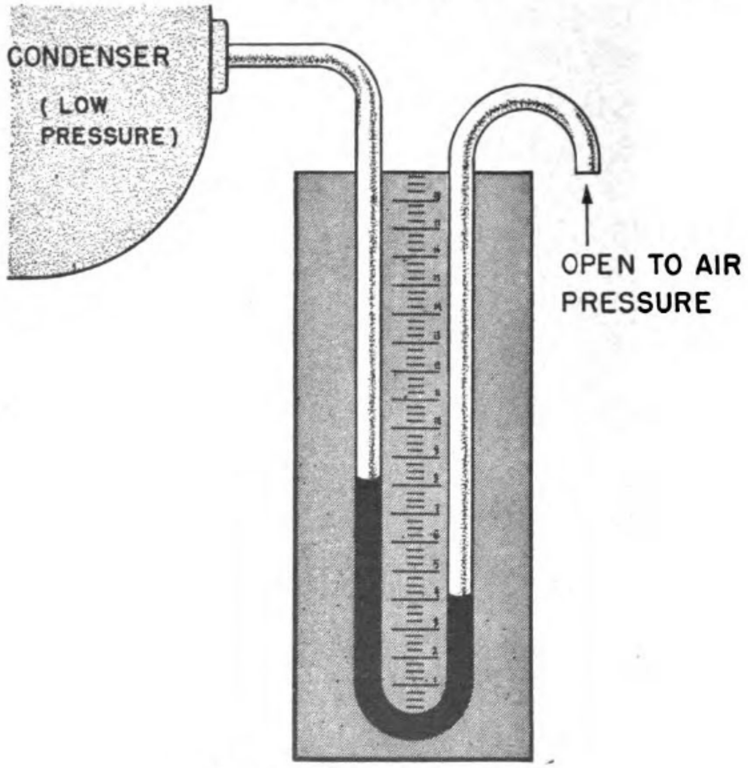



Figure 82.—A manometer.

turbine and causes the rotor to turn. After it has passed through the turbine it still exerts a back pressure against the blades. You can see that this is bad. Soon the back pressure would be nearly as large as that of the incoming steam, and the turbine would not turn at all. To reduce the back pressure as much as possible, the exhaust steam is run through pipes which are surrounded by cold sea water. This causes the steam in the pipes to condense into water, and the pressure drops well below atmospheric pressure.

It is important for the engineer to know the pressure in the condensers at all times. To measure this REDUCED pressure, or partial vacuum, he uses a gage called a MANOMETER. Figure 82 shows you how this simple device is made. A U-shaped tube has one end connected to the low-pressure condenser and the other end is open to the air. The tube is partly filled with colored water. The normal air pressure on the open end exerts a bigger push on the colored water than the push of the low-pressure steam, and the colored water is forced part way up into the left arm of the tube. From the scale between the two arms of the U, the difference in the height of the two columns of water can be read. This tells the engineer the degree of vacuum—or how much below atmospheric pressure the pressure is in the condenser.

## WHAT TO REMEMBER

Here are seven points that you should remember—

A FORCE is a push or a pull exerted on—or by—an object.

FORCE is generally measured in pounds.

PRESSURE is the FORCE PER UNIT AREA which is exerted on, or by, an object. It is commonly measured in pounds per square inch—psi.

Pressure is calculated by the formula $P = \frac{F}{A}$.

Spring scales and lever balances are familiar instruments you use for measuring FORCES. Bourdon gages, barometers, and manometers are instruments for the measurement of PRESSURE.

The NORMAL PRESSURE of the air is 14.7 psi at sea level.

PRESSURE is generally RELATIVE. It is sometimes GREATER—sometimes LESS—than normal air pressure. When PRESSURE is less than the normal air pressure, you call it VACUUM.

## CHAPTER 10

# HYDROSTATIC MACHINES

### LIQUIDS AT REST

You know that LIQUIDS EXERT PRESSURE. In order that your ship may remain afloat, the water must push upward on the hull. But the water is also exerting pressure on the sides. If you are billeted on a submarine, you are more conscious of water pressure—when you're submerged the sub is being squeezed from ALL sides. If your duties include deep-sea diving, you'll go over-side pumped up like a tire so that you can withstand the terrific force of the water below. The pressure exerted by the sea water, OR by any LIQUID AT REST, is called HYDROSTATIC PRESSURE. In handling torpedoes, mines, depth charges, and some types of aerial bombs, you'll be dealing with devices which are operated by hydrostatic pressure.

### PRESSURE DEPENDS UPON HOW DEEP YOU GO

In Chapter 9, you found out that all fluids exert pressure in all directions. That's simple enough.

But HOW GREAT is the pressure? Try a little experiment. Place a pile of blocks in front of you on the table. Stick the tip of your finger under the first block from the top. Not much pressure on your finger, is there? Stick it in between the third and fourth blocks. The pressure on your finger has increased. Now slide your finger under the bottom block in the pile. There you find the pressure is greatest. The pressure increases as you go lower in the pile. You might say that PRESSURE INCREASES WITH DEPTH. The same is true in liquids. The deeper you go, the greater the pressure becomes. But, DEPTH isn't the whole story.

## PRESSURE AT ANY DEPTH DEPENDS UPON THE LIQUID

Suppose the blocks in the preceding paragraph were made of lead. The pressure at any level in the pile would be considerably greater. Or, suppose they were blocks of balsa wood—the pressure at each level wouldn't be so great. Pressure, then, depends not only on the DEPTH, but also on the WEIGHT of the material. Since you are dealing with PRESSURE—force per unit of area—you will also be dealing with WEIGHT per unit of VOLUME—or DENSITY.

When you talk about the DENSITY of a substance you are talking about its weight per cubic foot—or per cubic inch. For example, the density of water is 62.5 lb. per cu. ft. This gives you a more exact way of comparing the weights of two materials. To say that lead is heavier than water isn't a complete statement. A 22-caliber bullet doesn't weigh as much as a pail of water. It is true, however, that a cubic foot of lead is lots heavier than a cubic foot of water. Lead has a GREATER DENSITY than water. The density of lead is 710 lb. per cu. ft., as compared with 62.5 lb. per cu. ft. for water.

Pressure depends on two factors—DEPTH and DENSITY—so it is easy to write a formula that will help you find the pressure at any depth in any liquid. Here it is—

$$P = H \times D$$

in which

$P$ = pressure, in lb. per sq. in., or lb. per sq. ft.
$H$ = depth of the point, measured in feet or inches.

and

$D$ = density in lb. per cu. in. or in lb. per cu. ft.

NOTE: If inches are used, they must be used throughout; if feet are used, they must be used throughout.

What is the pressure on one square foot of the surface of a submarine if the submarine is 200 feet below the surface? Use the formula—

$$P = H \times D$$

and

$$P = 200 \times 62.5 = 12{,}500 \text{ lb. per sq. ft.}$$

Every square foot of the sub's surface which is at that depth has a force of over 6 tons pushing in on it. If the height of the hull is 20 feet, and the area in question is midway between the sub's top and bottom, you can see that the pressure on the hull will be at least $(200-10) \times 62.5 = 11{,}875$ lb. per sq. ft., and the greatest pressure will be $(200+10) \times 62.5 = 13{,}125$ lb. per sq. ft. Obviously, the hull has to be made very strong to withstand such pressures.

## PRESSURE FIRES THE ASHCAN

Although hiding below the surface exposes the sub to great fluid pressure, it also provides the sub with a great advantage. A submarine is hard to kill because it is hard to hit. A depth charge must explode within 30 to 50 feet of a submarine to really score. And that means the depth charge must not go off until it has had time to sink to approximately the same level as the sub. You use a firing mechanism which is set off by the pressure at the estimated depth of the submarine.

Figure 83 shows you how this depth mechanism operates. A depth charge is a sheet-metal barrel filled with cast TNT. A tube passes through its center from end to end. Fitted in one end of this tube is the BOOSTER, which is a load of granular TNT

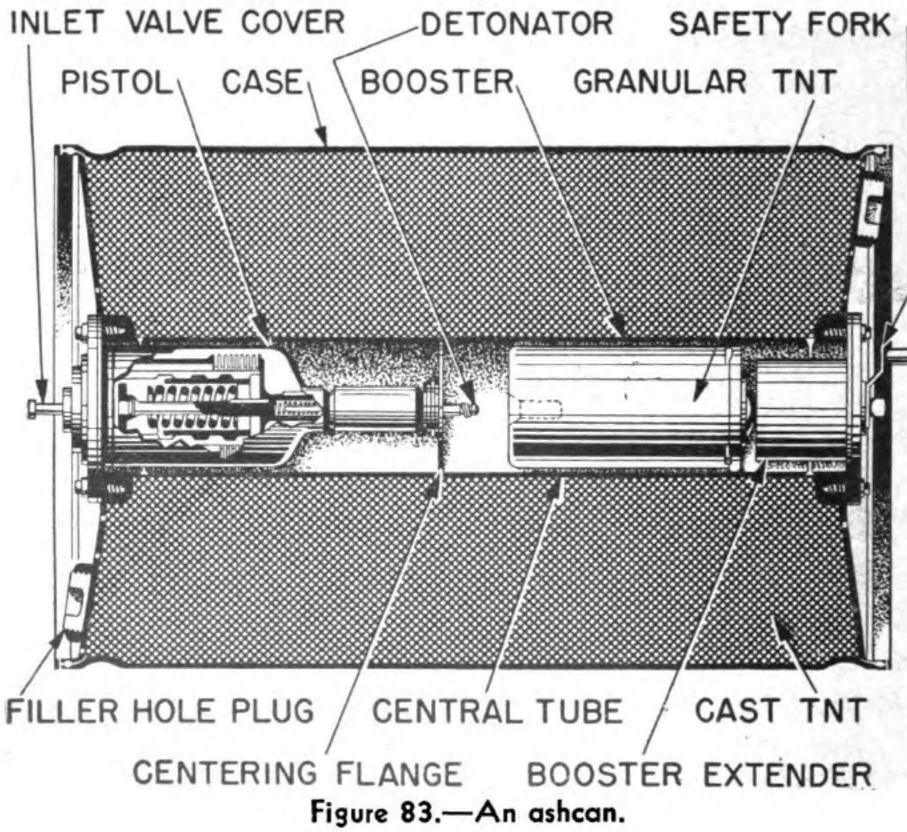



Figure 83.—An ashcan.

to set off the main charge. The safety fork is knocked off on launching, and the inlet valve cover is removed from an inlet through which the water enters.

When the depth charge gets about 12 to 15 feet below the surface, the water pressure is sufficient to extend a bellows in the booster extender. The bellow trip a release mechanism, and a spring pushes the booster up against the centering flange. Notice that the detonator fits into a pocket in the booster. Unless the detonator is in this pocket, it cannot set off the booster charge.

Nothing further happens until the detonator is fired. As you can see, the detonator is held in the end of the pistol, with the firing pin aimed at the detonator base. The pistol also contains a bellows into which the water rushes as the can goes down. As the pressure increases, the bellows begin to expand against the depth spring. You can adjust this spring so that the bellows will have to exert a predetermined force in order to compress it. Figure 84 shows you the depth-setting dials of one type of depth charge. Since the pressure on the bellows depends directly on the depth, you can arrange to have the charge go off at any depth you select on the dial. When the pressure in the bellows becomes sufficiently great it releases the firing spring, which drives the firing pin into the detonator. The booster, already moved left into position, is fired, and this in turn sets off the entire load of TNT.

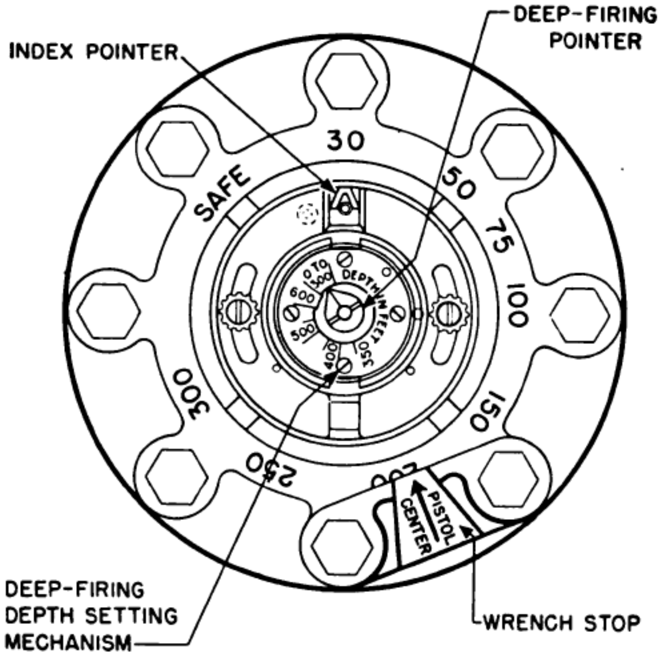



Figure 84.—You select the depth on these dials.

These two bellows—operated by hydrostatic pressure—serve two purposes. First they permit the depth charge to be fired at the proper depth; second, they make the charge safe to handle and carry. If the safety fork and the valve inlet cover should accidentally be knocked off on deck, nothing would happen. Even if the detonator went off while the charge was being handled, the main charge would not let go unless the booster were in the extended position.

To keep a torpedo on the course toward its target is quite a job. Maintaining the proper compass course by the use of a gyroscope is only part of the problem. The torpedo must travel at the proper depth so that it will neither pass under the target ship nor hop out of the water on the way. Here again hydrostatic pressure is used to advantage.

As figure 85 indicates, the tin fish contains an air-filled chamber which is sealed with a thin, flexible metal plate, or diaphragm. This diaphragm can bend upward or downward against the spring. The tension on this spring is determined by setting the depth-adjusting knob.

Suppose the torpedo starts to dive BELOW the selected depth. The water, which enters the torpedo and surrounds the chamber, exerts an increased pressure on the diaphragm and causes it to bend DOWN. If you follow the lever system, you can see that the pendulum will be pushed forward. Notice that a valve rod connects the pendulum to the piston of the depth engine. As the piston moves to the left, low-pressure air from the torpedo's air supply enters the depth engine to the right of the piston and pushes it to the left. A depth engine must be used because the diaphragm is not strong enough to move the rudders.

The depth-engine's piston is connected to the horizontal rudders as shown. When the piston moves to the left, the rudder is turned upward, and the torpedo begins to rise to the proper depth. If the nose goes up, the pendulum tends to swing backward and keep the rudder from elevating the torpedo too rapidly. As long as the torpedo runs at the selected depth, the pressure on the chamber remains constant, and the rudders do not change from their horizontal position.

## IN DAVY JONES' LOCKER

Navy divers have a practical, first-hand knowledge of hydrostatic pressure. Think what happens to a diver who goes down 100 feet to work on a salvage job. The pressure on him at that depth is 6,250 lbs.

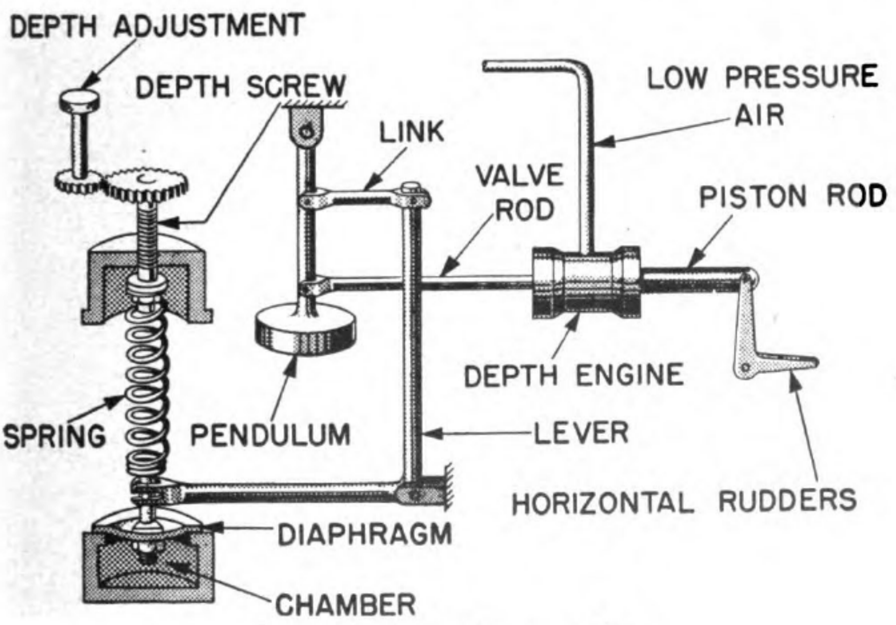


Figure 85.—Inside a torpedo.

per sq. ft.! Something must be done about that, or he'd be squashed flatter than a pancake.

To counterbalance this external pressure, the diver is enclosed in a rubber suit into which air under pressure is pumped by a shipboard compressor. Fortunately, the air not only inflates the suit, but gets inside of the diver's body as well. It enters his lungs, and even gets into his blood stream which carries it to every part of his body. In that way his internal pressure can be kept just equal to the hydrostatic pressure.

As he goes deeper, the air pressure is increased to meet that of the water. In coming up, the pressure on the air is gradually reduced. If he is brought up too rapidly, he gets the "bends." The air which was dissolved in his blood begins to come out of solution, and form as bubbles in his veins. Any sudden release in the pressure on a fluid results in

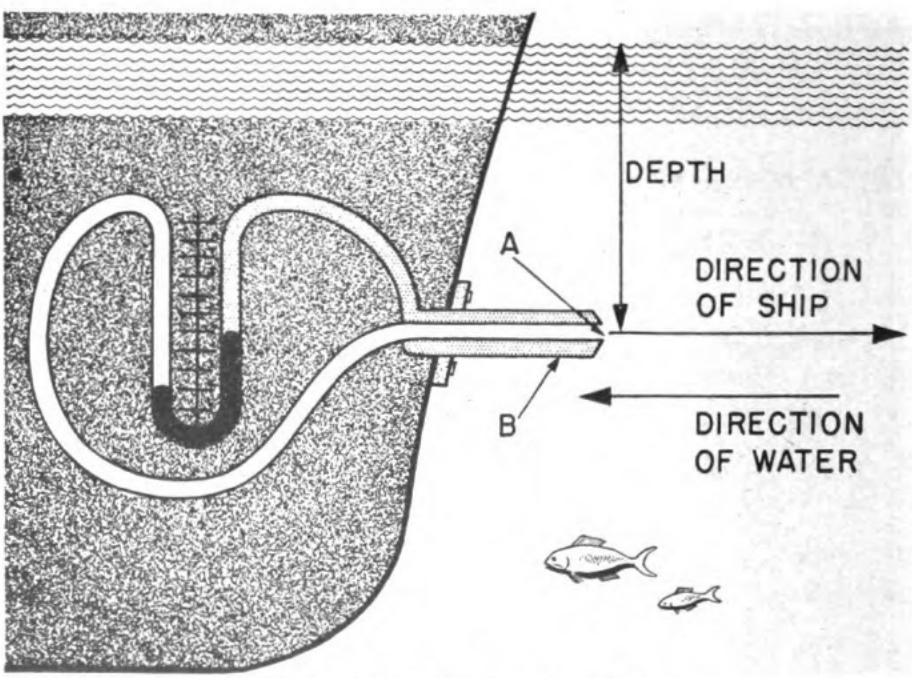



**Figure 86.—A pitometer log.**

freeing some of the gases which are dissolved in the fluid.

You have seen this happen when you suddenly relieve the pressure on a bottle of pop by removing the cap. The careful matching of hydrostatic pressure on the diver by means of air pressure in his suit is essential if diving is to be done at all.

## A SEA-GOING SPEEDOMETER

Here's another device that shows you how your Navy applies its knowledge of hydrostatic pressure.

Did you ever wonder how the skipper knows the speed the ship is making through the water? There are several instruments used to give this information—the patent log, the engine revolution counter, and the pitometer log. The "PIT. LOG" is operated, in part, by hydrostatic pressure. It really indicates the DIFFERENCE between hydrostatic pressure and the pressure of the water flowing past the ship. But you can use this DIFFERENCE to indicate ship's speed.

Figure 86 shows you a schematic drawing of a pitometer log. A double-wall tube sticks out forward of the ship's hull into water which is not disturbed by the ship's motion. In the tip of the tube is an opening *A*. When the ship is moving there are two forces or pressures acting on this opening—the HYDROSTATIC PRESSURE due to the depth of water above the opening, and a PRESSURE caused by the push of the ship through the water. The total pressure from these two forces is transmitted through the central or white tube to the left-hand arm of a manometer.

In the SIDE of the tube is a second opening *B* which does NOT face in the direction the ship is moving. Opening *B* passed through the outer wall of the double-wall tube, but not through the inner wall. The ONLY PRESSURE affecting this opening *B* is the HYDROSTATIC PRESSURE. This pressure is transmitted through the outer tube (shaded in the drawing) to the right-hand arm of the manometer.

When the ship is dead in the water, the pressure through both openings *A* and *B* is the same, and the mercury in each arm of the manometer stands at the same level. However, as soon as the ship begins to move, additional pressure is developed at opening *A*, and the mercury is pushed down in the left-hand arm and up into the right-hand arm of the tube. The faster the ship goes, the greater this additional pressure becomes, and the greater the difference will be between the levels of the mercury in the two arms of the manometer. The speed of the ship can be read directly from the CALIBRATED SCALE on the manometer.

Incidentally—since air is also a fluid—the air-speed of an aircraft can be found by a similar device. You have probably seen the thin tube sticking out from the leading edge of a wing, or from the nose of the plane. Flyers call this tube a PITOT TUBE. Its fundamental principle is the same as that of the pitometer log.

## WHAT D'YA KNOW?

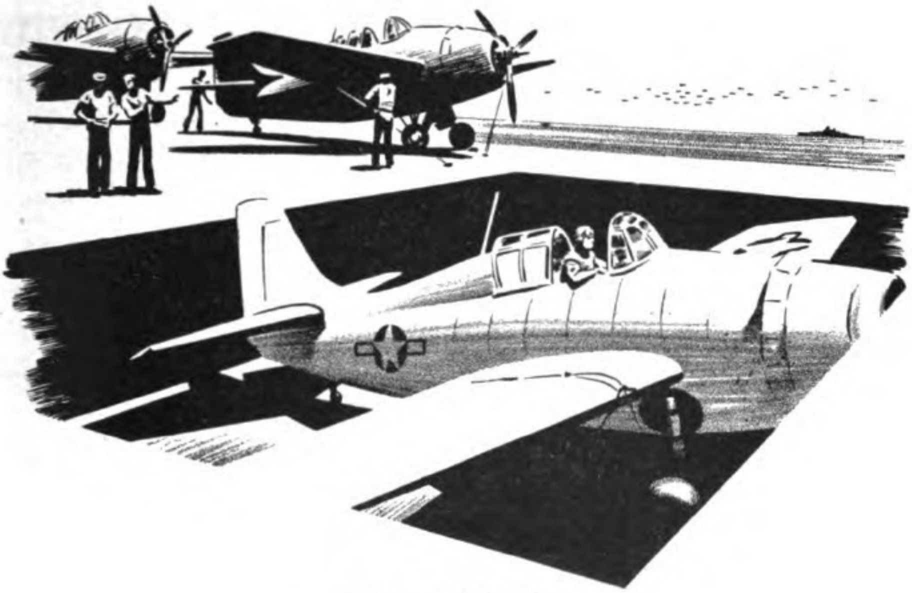
The Navy uses many devices whose operation is dependent on the hydrostatic principle. Here are three points to remember about the operation of these devices.

PRESSURE in a liquid is exerted equally in ALL DIRECTIONS.

You use the term HYDROSTATIC PRESSURE when you are talking about the pressure at any depth in a liquid that is not flowing.

Pressure depends upon both depth and density. The formula for finding pressure is—

$$P = H \times D$$



## CHAPTER 11

# HYDRAULIC MACHINES

## BARBER CHAIRS TO FOUR-WHEEL BRAKES

Perhaps your earliest contact with a hydraulic machine was when you got your first haircut. Tony put a board across the arms of the chair, sat you on it, and began to pump the chair up to a convenient level. As you grew older, you probably discovered that the filling station attendant could put a car on the greasing rack, and—by some mysterious arrangement—jack it head-high. No doubt the attendant told you that oil under pressure below the piston was doing the job.

Come to think about it, you've probably known something about hydraulics for a long time. Automobiles and airplanes use hydraulic brakes. As a bluejacket, you'll have to operate many hydraulic machines, so you'll want to understand the basic principles on which they work.

## APPLYING FORCES

Simple machines such as the lever, the inclined plane, the pulley, the wedge, and the wheel and axle, were used by primitive man. But it was considerably later before someone discovered that liquids and gases could be used to exert forces at a distance. Then, a vast number of new machines appeared. A machine which transmits forces by means of a liquid is a HYDRAULIC MACHINE. A variation of the hydraulic machine is the type that operates by the use of a compressed GAS. This type is called the PNEUMATIC machine. This chapter deals only with BASIC HYDRAULIC MACHINES.

## THE WHYS AND WHEREFORES

A Frenchman named Pascal discovered that a pressure applied to any part of a confined fluid is transmitted to EVERY OTHER PART WITH NO LOSS. THE PRESSURE ACTS WITH EQUAL FORCE ON ALL EQUAL AREAS OF THE CONFINING WALLS, AND PERPENDICULAR TO THE WALLS.

But remember this—when you are talking about the hydraulic principle as applied to a hydraulic machine, you are talking about the way a liquid acts in a CLOSED SYSTEM of pipes and cylinders. The ac-

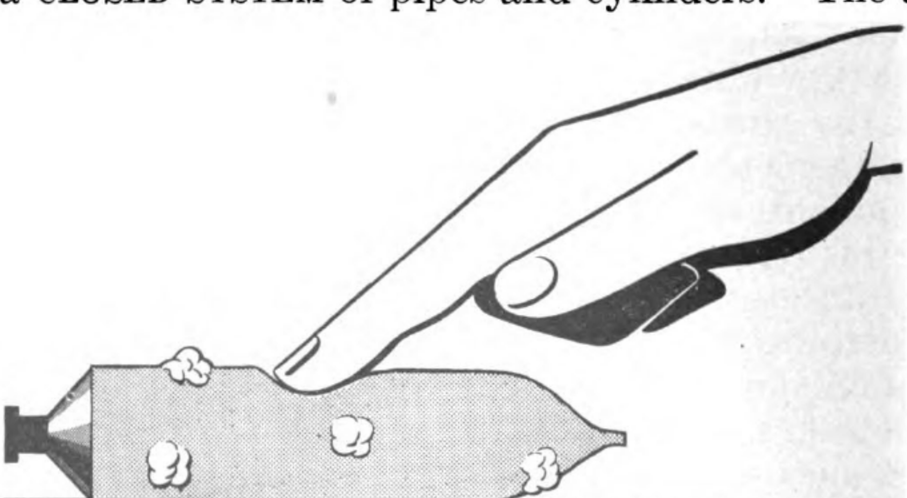


Figure 87.—Pressure is transmitted in all directions.

tion of a liquid under such conditions is somewhat different from its behavior in open containers, or in lakes, rivers, or oceans. You should also keep in mind that most liquids cannot be compressed—squeezed into a smaller space. Liquids don't "give" the way air does when pressure is applied, nor do liquids expand when pressure is removed.

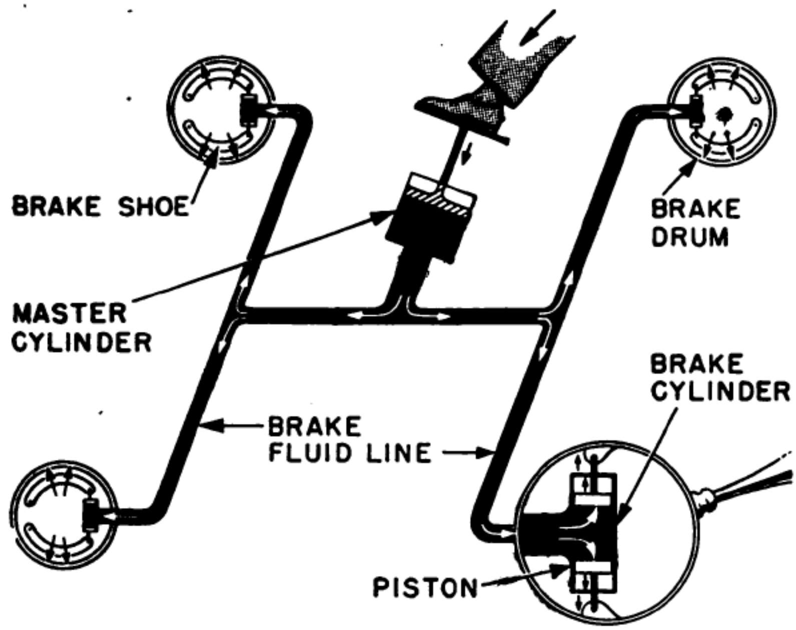



**Figure 88.—Hydraulic brakes.**

Punch a hole in a tube of shaving cream. If you push down at any point on the tube the cream comes out of the hole. Your force has been transmitted from one place to another by the shaving cream—which is fluid—a thick liquid. Figure 87 shows what would happen if you punched four holes in the tube. If you press on the tube at one point, the cream comes out of all four holes. This tells you that a force applied on a liquid is transmitted equally in every direction to all parts of the container. Right there you have illustrated a basic principle of HYDRAULIC MACHINES.

This principle is used in the operation of four-wheel hydraulic automobile brakes. Figure 88 is a simplified drawing of this brake system. You push down on the brake pedal and force the piston in the master cylinder against the fluid in that cylinder. This push sets up a pressure on the fluid just as your finger did on the shaving cream in the tube. The pressure on the fluid in the master cylinder is transmitted through the lines to the brake cylinders in each wheel. This fluid under pressure pushes against the pistons in each of the brake cylinders and forces the brake shoes out against the drums.

## HOW BIG IS THE FORCE?

The next thing to understand about hydraulic machines is the relationship between the force you apply and the result you get. Figure 89 will help you on this. The U-shaped tube has a cross-sectional area of one sq. in. In each arm there's a

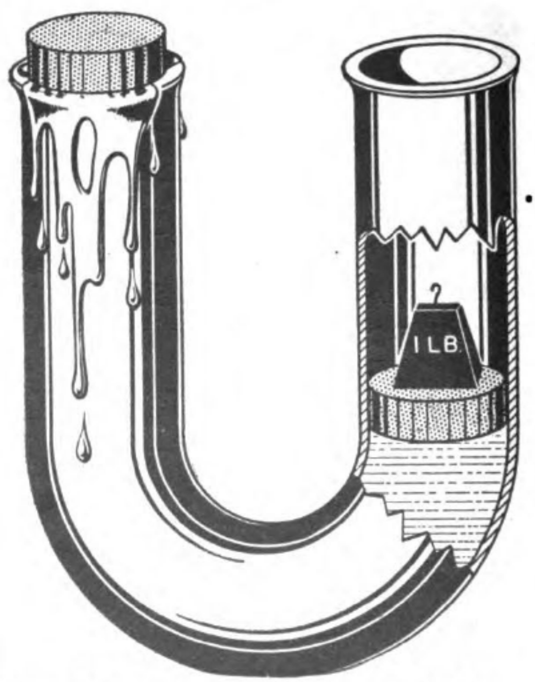



**Figure 89.—The liquid transmits the force.**

piston which fits snugly, but which can move up and down. If you place a one-pound weight on one piston, the other will be pushed out the top of its arm immediately. Place a one-pound weight on EACH piston, however, and they remain in their original positions, as shown in figure 90.

Thus you see that a pressure of one pound per sq. in. applied downward on the right-hand piston exerts a pressure of one pound per sq. in. upward against the left-hand one. In other words, not only is the

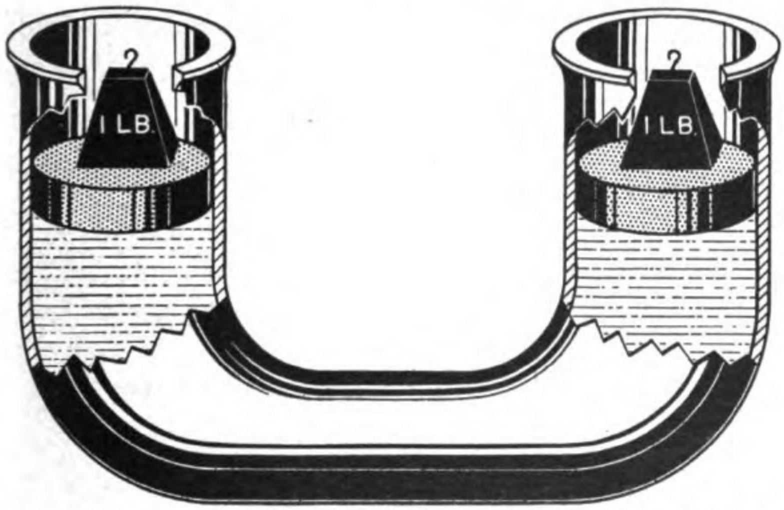



**Figure 90.—Pressure is the same on all parts of an enclosed liquid.**

force transmitted by the liquid around the curve, but the FORCE IS THE SAME ON EACH UNIT AREA OF THE CONTAINER. IT MAKES NO DIFFERENCE HOW LONG THE CONNECTING TUBE IS, OR HOW MANY TURNS IT MAKES. It is important, however, that the entire system be full of liquid. Hydraulic systems will fail to operate properly if air is present in the lines or cylinders.

Now look at figure 91. The piston on the right has an area of one sq. in., but the piston on the left has an area of 10 sq. in. If you push down on the smaller piston with a force of one pound, the liquid will transmit this pressure to EVERY SQUARE INCH of surface in the system. Since the left-hand piston has an area of 10 sq. in., and each square inch has a force of one pound transmitted to it, the total effect is to push on the larger piston with a total force of 10 pounds. Set a 10-pound weight on the larger piston and it will be supported by the one-pound force of the smaller piston.

There you have a one-pound push resulting in a 10-pound force. That's a mechanical advantage of TEN. This is why HYDRAULIC MACHINES are impor-

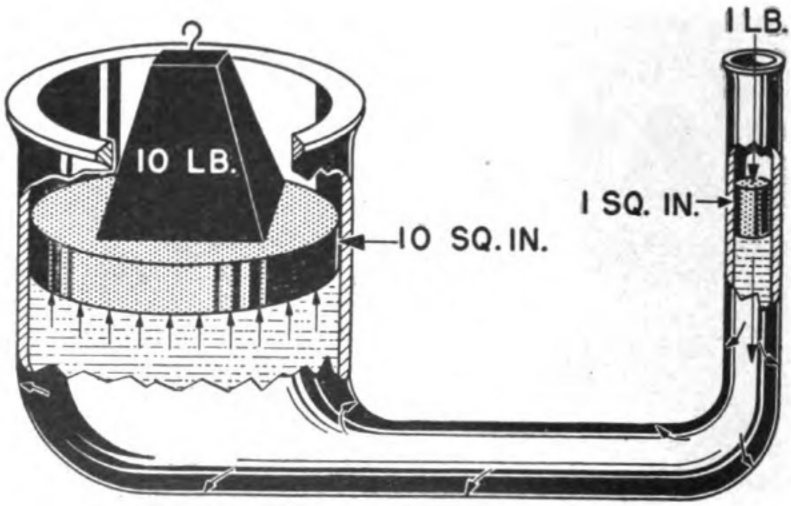



**Figure 91.—A mechanical advantage of 10.**

tant. Here's a formula which will help you to figure the forces that act in a hydraulic machine—

$$\frac{F_1}{F_2}=\frac{A_1}{A_2}$$

In which $F_1$ = force, in pounds, applied to the small piston,

$F_2$ = force, in pounds, applied to the large piston,

$A_1$ = area of small piston, in square inches,

$A_2$ = area of large piston, in square inches.

Try out the formula on the hydraulic press in figure 92. The large piston has an area of 90 sq. in. and the smaller one an area of two sq. in. The handle exerts a total force of 15 pounds on the small piston. With what total force will the large piston be raised?

Write down the formula—

$$\frac{F_1}{F_2}=\frac{A_1}{A_2}$$

Substitute the known values—

$$\frac{15}{F_2}=\frac{2}{90}$$

and—

$$F_2=\frac{90\times15}{2}=675 \text{ pounds.}$$

## WHERE'S THE CATCH?

You know from your experience with levers that you can't get something for nothing. Applying this knowledge to the simple system in figure 90, you know that you can't get a 10-pound force from a one-pound effort without sacrificing distance. The one-pound effort will have to be applied through a much greater distance than the 10-pound force will move.

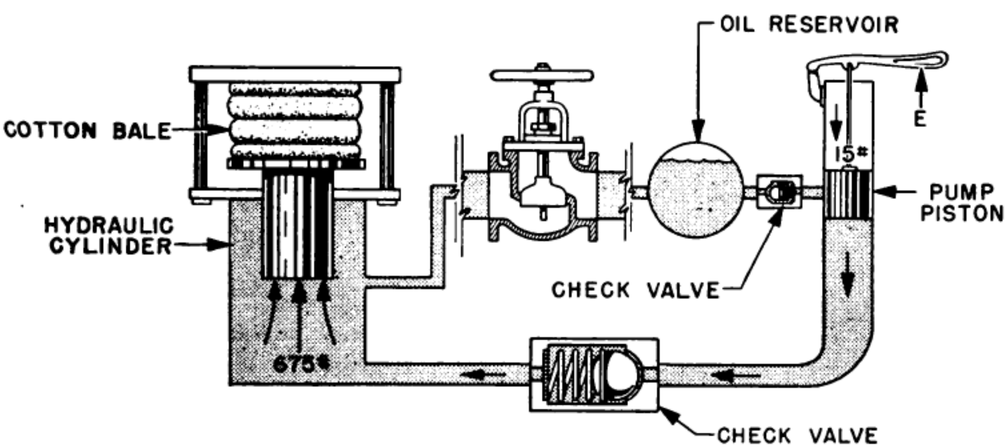



**Figure 92.—Hydraulic press.**

If you raise the 10-pound weight through a distance of one foot, through what distance will the one-pound effort have to be applied? Remember—if you neglect friction, the work done ON any machine equals the work done BY that machine. Use the WORK FORMULA, and you can find how far the smaller piston will have to move.

$$\text{Work input}=\text{Work output}$$

$$F_1\times D_1=F_2\times D_2$$

By substituting— $1 \times D_1 = 10 \times 1$

and— $D_1 = 10$ feet

There's the catch. The smaller piston will have to move through a distance of 10 feet in order to raise the 10-pound load one foot. It looks then as though the smaller cylinder would have to be at least 10 feet long—and that wouldn't be practical. Actually, it isn't necessary—if you put a VALVE in the system.

The hydraulic press in figure 92 contains a valve for just this purpose. As the small piston moves down, it forces the fluid past the CHECK VALVE *A* into the large cylinder. As soon as you start to move the small piston upward, the pressure to the right of the check valve *A* is removed, and the pressure of the fluid below the LARGE PISTON helps the check-valve spring force that valve shut. The liquid which has passed through the valve opening on the down stroke of the small piston is trapped in the large cylinder.

The small piston rises on the up-stroke until its bottom passes the opening to the fluid reservoir. More fluid is sucked past a check valve *B* and into the small cylinder. The next down-stroke forces this new charge of fluid out of the small cylinder past the check valve into the large cylinder. This process is repeated stroke by stroke until enough fluid has been forced into the large cylinder to raise the large piston the required distance of one foot. The force has been applied through a distance of 10 feet on the pump handle, but it was done by making a series of relatively short strokes—the SUM of all the strokes being equal to 10 feet.

Maybe you're beginning to wonder how the large piston gets back down after you've baled the cotton. The fluid can't run back past the check valve *B*—that's obvious. You lower the piston by letting the oil flow back to the reservoir through a return line. Notice that a simple GATE VALVE is inserted in this line. When the gate valve is opened, the fluid flows back into the reservoir. Of course, this valve is kept shut while the pump is in operation.

## LEFT STANDARD RUDDER!

You've probably seen the steersman swing a ship weighing thousands of tons about as easily as you turn your car. Nope, he's not SUPERMAN. He does

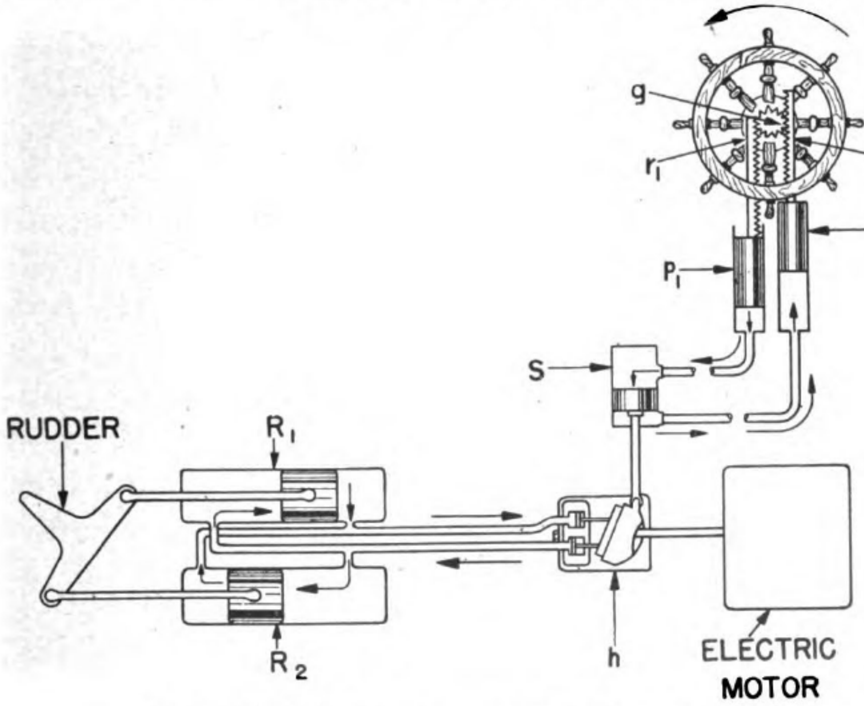



Figure 93.—Steering is easy with this machine.

it with machines. Many of these machines are HYDRAULIC. There are several types of hydraulic and electro-hydraulic steering mechanisms, but the simplified diagram in figure 93 will help you to understand the general principles of their operation. As the hand steering wheel is turned in a counter-clockwise direction, its motion turns the pinion gear *g*. This causes the left-hand rack $r_1$ to move downward, and the right-hand rack $r_2$ to move upward. Notice that each rack is attached to a piston $p_1$ or $p_2$.

The downward motion of rack $r_1$ moves piston $p_1$ downward in its cylinder and pushes the oil out of that cylinder through the line. At the same time, piston $p_2$ moves upward and pulls oil from the right-hand line into the right-hand cylinder.

If you follow these two lines, you see that they enter a hydraulic cylinder $S$—one line entering ABOVE and one BELOW the single piston in that cylinder. In the direction of the oil flow in the diagram, this piston and the attached plunger are pushed down toward the hydraulic pump $h$. So far, in this operation, you have used HAND POWER to develop enough oil pressure to move the control plunger attached to the hydraulic pump. At this point an electric motor takes over and drives the pump $h$.

Oil is pumped under pressure to the two big steering rams $R_1$ and $R_2$. You can see that the pistons in these rams are connected directly to the rudder crosshead which controls the position of the rudder. With the pump operating in the direction shown, the ship's rudder is thrown to the left, and the bow will swing to port. This operation demonstrates how a small force applied on the steering wheel sets in motion a series of operations which result in a force of thousands of pounds.

## PLANES ON DECK

The swift, smooth power required to get airplanes from the hangar deck to the flight deck of a carrier is supplied by a HYDRAULIC LIFT. Figure 93 explains how this lifting is done. A variable-speed gear pump is driven by an electric motor. Oil enters the pump from the reservoir and is forced through the lines to four hydraulic rams, the pistons of which raise the elevator platform. The oil under pressure exerts its force on each square inch of surface area of the four pistons. Since the pistons are large, a large total lifting force results. The elevator can be lowered by

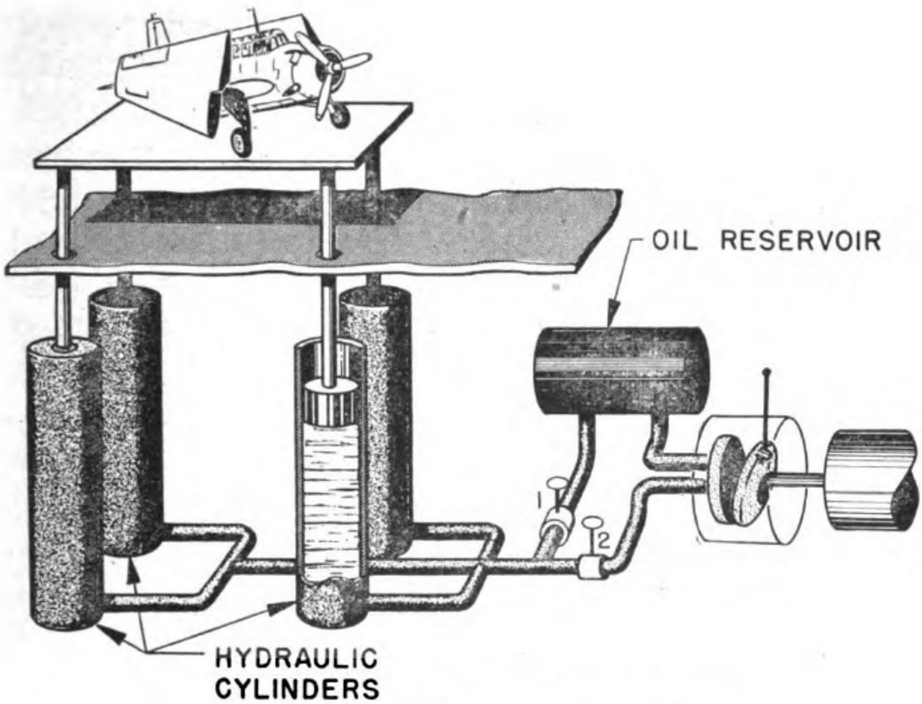



Figure 94.—This gets them there in a hurry.

reversing the pump, or by opening valve 1 and closing valve 2. The weight of the elevator will then force the oil out of the cylinders and back into the reservoir.

## SUBMARINE HYDRAULICS

Here's another application of HYDRAULICS which you will find interesting. Inside a submarine, between the outer skin and the hull, are several ballast tanks which are used to control the total weight of the ship, and allow it to submerge or rise. When these

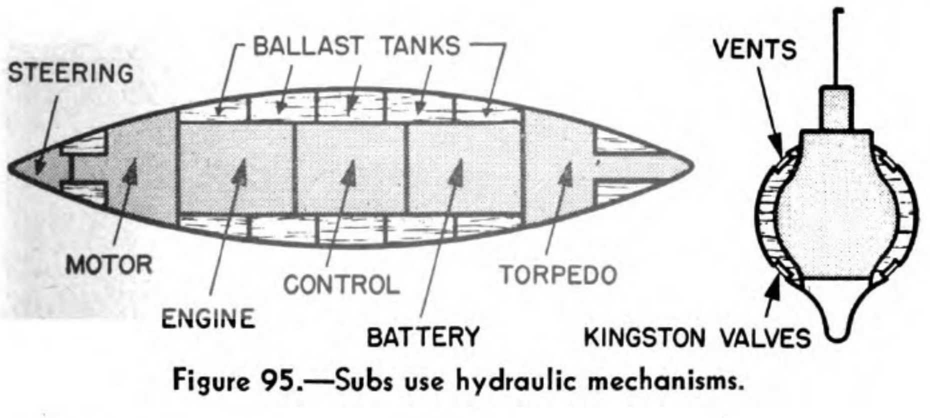



Figure 95.—Subs use hydraulic mechanisms.

are flooded with sea water the boat becomes "heavy" and can be easily driven below the surface by giving the diving planes a "down" angle. But if you blow compressed air into the tanks and force the water out of the ballast tanks, the sub becomes "light," and rises to the surface. There are main tanks, regulator tanks, and bow and stern trimming tanks. Figure 95 shows you where these tanks are located.

When the sub is on the surface and about to dive, the main tanks are filled. Then enough water is let into the regulators to give only a slight buoyancy—a few hundred pounds. The sub will then slide under with the help of the horizontal planes. Once below, the trimming tanks are "watered" to give her exact fore-and-aft balance.

As diving is a high-speed operation, the tanks must be filled quickly. This is done by opening large KINGSTON VALVES in the sub ballast tanks. These valves let the water flood in, and at the same time open vents on the tank tops so that whatever air which is present in the tanks is expelled. Each tank has several kingstons, and the whole system can be flooded in about 60 seconds.

In the normal submerged run, the kingstons are left open, and the vents are closed. The tanks are then full. When the skipper decides to surface the vents and kingstons remain in the same position as for a submerged run; but now the tanks are "blown" with high pressure air, carried in large quantities for that purpose. The compressed air is furnished by large compressors in the engine or motor room, and is stored at a pressure of about 3,000 psi, in a group of steel bottles in the bilges.

The openings to the vents and kingstons are outside the hull, so some means of remote control is necessary if they are to be opened and closed from within the sub. For this purpose hydraulic pumps, lines, and rams are used. Oil pumped through tubing which passes outside of the hull to the valves operates the valves by pushing on a piston in a hydraulic cylinder. It is simpler to operate the vents and kingston valves by a hydraulic system from the control room than it would be to operate them by a mechanical system of gears and levers. The lines can be readily led around obstructions and corners within the hull, and minimum of moving parts is necessary.

## AN ACCUMULATOR

In most hydraulic systems, you keep oil under pressure in a container called an ACCUMULATOR. Figure 96 shows you this large cylinder, into the top of which oil is pumped. A free piston divides the cylinder into two parts. Compressed air is forced in BELOW the piston at a pressure of, say, 600 psi. Oil is then forced in on TOP of the piston. As the pressure above it increases, the piston is forced down, and squeezes the air into a smaller space. Air is elastic—it can be compressed under pressure—but it will expand as soon as the pressure is reduced. When oil pressure is reduced, relatively large quantities of oil under working pressure are instantly available to operate hydraulic rams or motors any place on the sub.

## WHAT'S THE SCORE?

The working principle of all hydraulic mechanisms is simple enough. Whenever you find an application that seems a bit hard to understand, keep these points in mind—

HYDRAULICS is the term applied to the behavior of ENCLOSED liquids. Machines which are operated by liquids under pressure are called HYDRAULIC MACHINES.

Liquids are incompressible. They cannot be squeezed into spaces smaller than they originally occupied.

A force applied on any area of a confined liquid is transmitted equally to every part of the liquid.

In hydraulic cylinders, the relation between the force exerted by the larger piston to the force applied on the smaller piston is the same as the relation between the area of the larger piston and the area of the smaller piston.

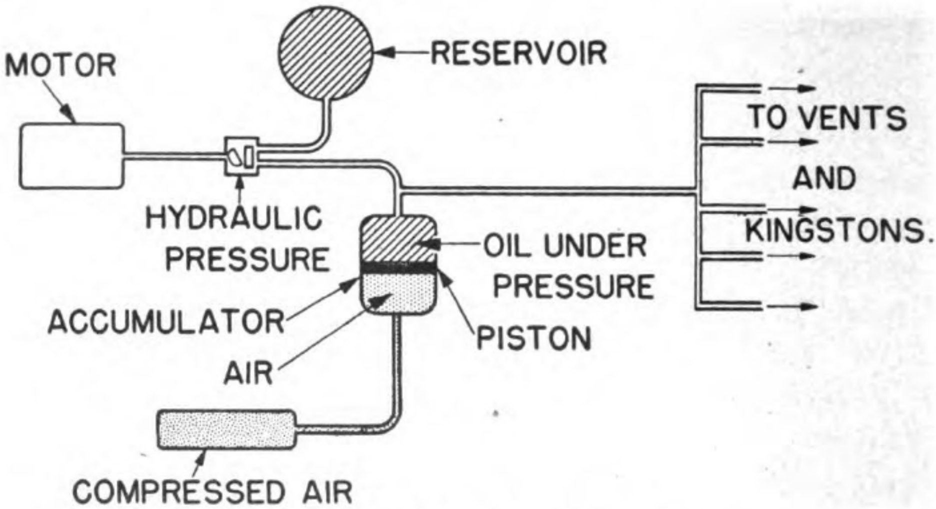



**Figure 96.—This keeps pressure on top.**

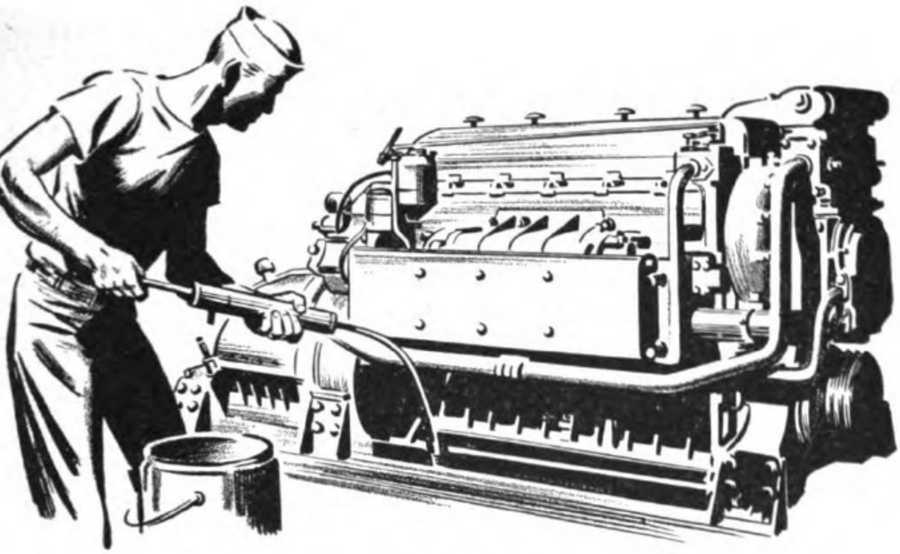
Some of the advantages of hydraulic machines are—

Tubing is used to transmit forces, and tubing can readily transmit forces around corners.

Little space is required for tubing.

Few moving parts are required.

Efficiency is high, generally 80–95%.



## CHAPTER 12

# COMPLEX MACHINES

### PORTHOLE CLOSER—BLANKET PULLER-UPPER

Take a good look at figure 97 and read the directions for operation. THIS MACHINE was invented by a guy named Oscar. Sea water entering open port is caught in helmet (*1*) hung on rubber band. Rubber stretches and helmet is pushed down against shaft of Australian spear (*2*). Head of spear tips over box of bird seed (*3*) which falls in cage (*4*) where parrot (*5*) bends over to pick it up. Board strapped on parrot's back pulls on string (*6*) which releases arrow (*7*) and slams the port shut. Breeze from closing port turns page on calendar (*8*) to new day.

In the meantime, water falling over waterwheel (*9*) turns gears (*10*) which wind string (*11*) on drum (*12*). This pulls blanket up over Oscar. Arm (*13*) pulls on cord (*14*) and raises board under alarm clock (*15*) sliding same into bucket of water.

In case of mechanical breakdown at any point in the system, helmet is tipped by off-center peg (*16*) emptying water into funnel (*17*). Pipe (*18*) directs water onto Elmer, who is sleeping below. The theory is that Elmer will get up and do SOMETHING about that open port—or about Oscar.

You'll probably agree that this nightmare is a COMPLEX MACHINE. But, if you look carefully, you can see that Oscar has put together several SIMPLE MACHINES to make this complicated device. He has used a couple of levers, several blocks, a gear train, and you can even find an inclined plane under the alarm clock.

While this gadget is nonsensical, it does call attention to the important fact that a COMPLEX MACHINE is nothing more than a combination of two or more SIMPLE MACHINES, conveniently arranged to do the job at hand. It makes no difference how big or complicated the machine is, you can figure out how it works if you understand the operation of the simple machines from which it is made. Just as you did with Oscar's Goldberg, always start at the point where the ENERGY is applied and follow the movement systematically, step-by-step, to the business end.

One of the first things you should learn is to recognize the simple machines which are included in a complex machine. If you use your eyes and your brain, you should be able to predict what will happen when a force is exerted at any point in any simple machine. Make a step-by-step analysis—and you'll find that complex machines are no longer complex or mysterious.

## FUEL-OIL-HATCH COVER

Here's a complex mechanism that is easy to figure out. The hatch cover in Figure 98 weighs a couple of hundred pounds; and the device which raises it is a complex machine. It is complex because it consists of TWO SIMPLE MACHINES—a JACKSCREW and a FIRST-CLASS LEVER.

First locate the point where you apply a force to

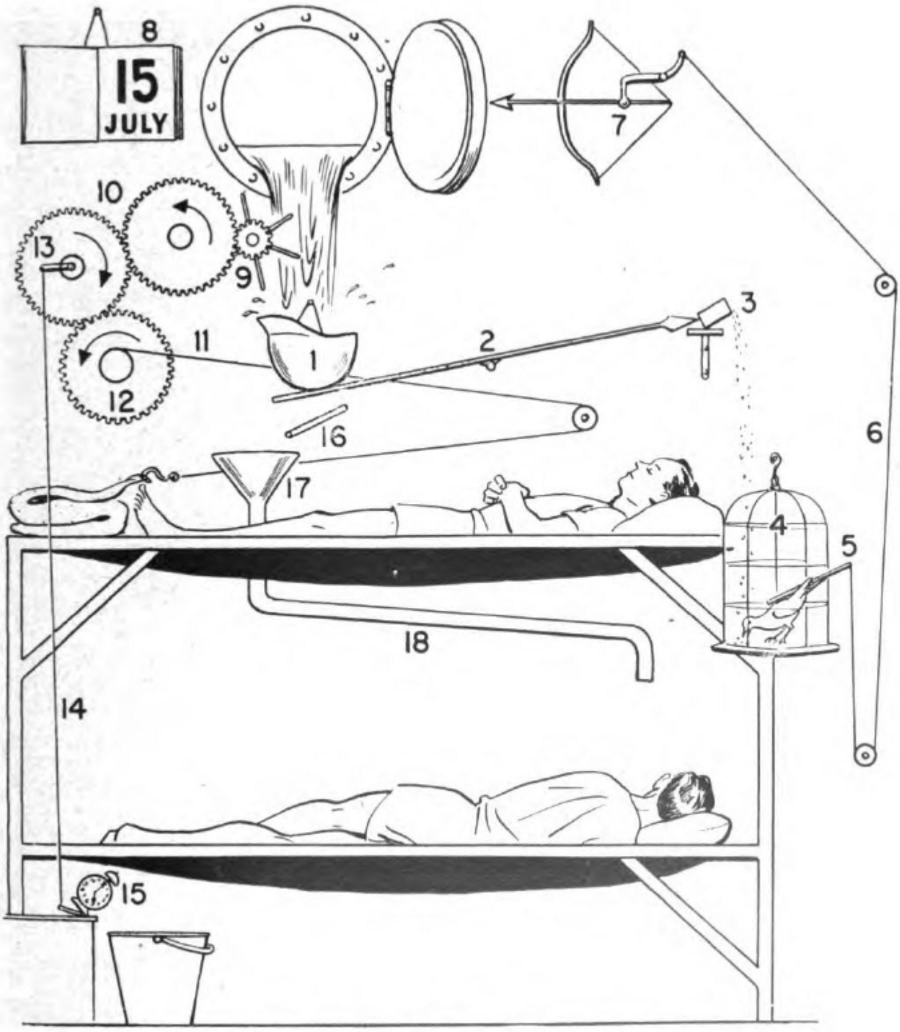



Figure 97.—A complex machine!

the machine. That WRENCH HANDLE seems a likely spot. Remember that you can consider this handle as if it were the spoke of a wheel. Suppose you turn this handle in a COUNTERCLOCKWISE direction. That

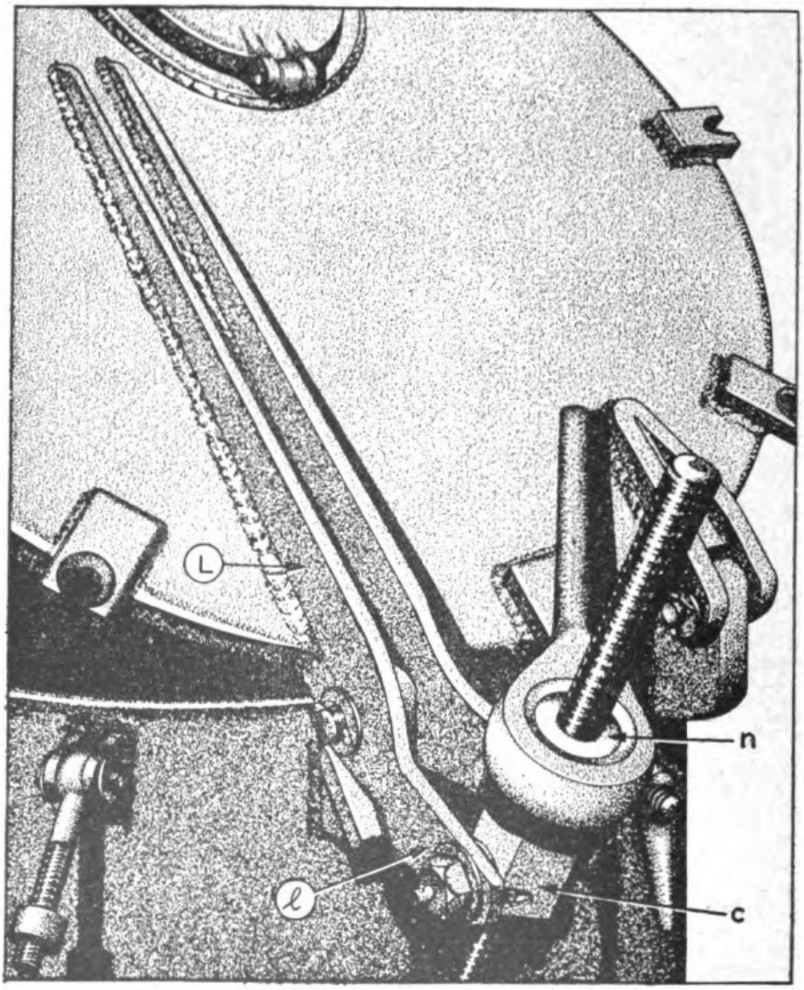


Figure 98.—A not-too-complex machine.

will cause the NUT *n* to move UPWARD along the threaded bolt. One complete turn of the handle will cause the nut to move upward a distance equal to the PITCH of the thread on the bolt. That COLLAR *c* follows the nut up and permits the lever arm 1 to rise. The other part of the lever arm L will move downward. Since 1 is much shorter than L, the downward movement of the cover will be much greater than the upward movement of the collar. It's a "speed-up" arrangement.

The hatch cover is CLOSED by turning the handle COUNTERCLOCKWISE, and is OPENED by turning the handle clockwise. This combination of two simple machines is better mechanically than one machine.

Here's how to go about figuring out how a complex machine works. Locate the point where the energy is applied and look over the part of the machine next there. You say to yourself, "Oh, yeah, this is really a jackscrew"—or a wheel and axle, or whatever the machine happens to be. "If I turn it clockwise, then the piece right here will move so. That's going to cause this arm to move to the right. And since the arm is part of a first-class lever, the other end will move over to here to the left." In every case, you follow through in a similar manner from one part to another—carefully determining the DIRECTION and MAGNITUDE of the motion.

Perhaps you will want to know the size of the force that is exerted at some point in the machine, or perhaps the mechanical advantage up to a point. Remember that the MECHANICAL ADVANTAGE of a COMPLEX MACHINE is equal to the PRODUCT of the mechanical advantage of each SIMPLE MACHINE from which it is made.

Assume some numerical values for the hatch cover in Figure 98 and see how you can calculate the mechanical advantage. For example, allow 18 inches for the length of the wrench from the end of the handle to the center of the bolt. Let the pitch of the thread be ¼ inch. The collar is attached to arm $l$ 5 inches from the fulcrum, and the center of the cover lies 18 inches from the fulcrum along arm $L$.

The theoretical mechanical advantage of the jackscrew can be found by using the formula—

$$\text{M. A.} = \frac{2\pi r}{p}$$

$$= \frac{2 \times 3.14 \times 18}{\frac{1}{4}} = \frac{113}{\frac{1}{4}} = 452$$

Since jackscrews rarely have an efficiency of better than 30 percent, you'd be wise to multiply this theoretical mechanical advantage by 0.30, which gives an actual mechanical advantage of $452 \times 0.30 = 136$ for this part of the machine.

Now figure what the lever action does for you. The theoretical mechanical advantage of a lever system can be found by dividing the length of the resistance arm by the length of the effort arm.

$$\text{M. A.} = \frac{l}{L} = \frac{5}{18} = 0.278$$

Notice that the lever gives you a mechanical advantage of LESS THAN ONE. Whenever the M. A. is less than one, you know that either the speed or the distance of motion has been magnified at the expense of force. In this case, you can afford to sacrifice force for distance.

The overall mechanical advantage of the machine is equal to the product of the two mechanical advantages, or $136 \times 0.278 = 37.8$.

That is the standard method of attack for figuring the M. A. of complex machines.

## A WATER-TIGHT DOOR

Figure 99 shows you a WATER-TIGHT DOOR—a complex machine that is a combination of a WHEEL-AND-AXLE and a system of LEVERS. That big center handle *A* is the POINT OF INPUT, which is the place to start. If you pull the handle to the right, point *a* on DRIVE LINK *1* moves to the right. That's going to make point *b* on the same link move to the left. Now look at DRAG LINK *2*.

It will be moved to the left. Point *a* on drag link *2* moves in the direction indicated by the arrow. That action moves the outer—or right-hand—end of the BELL-CRANK *3* upward, and the DOG is extended to the locking position. At the same time drag link *4* moves downward—because it is pivoted to the left-hand end of bell-crank *3*. If you follow the movement of link *4* you will see that as its end *a* moves down, it raises the end *b* of bell-crank *5* into the locking position.

Now come back to the end *b* of lever arm *2*. Its motion is indicated by the arrow. End *b* moves

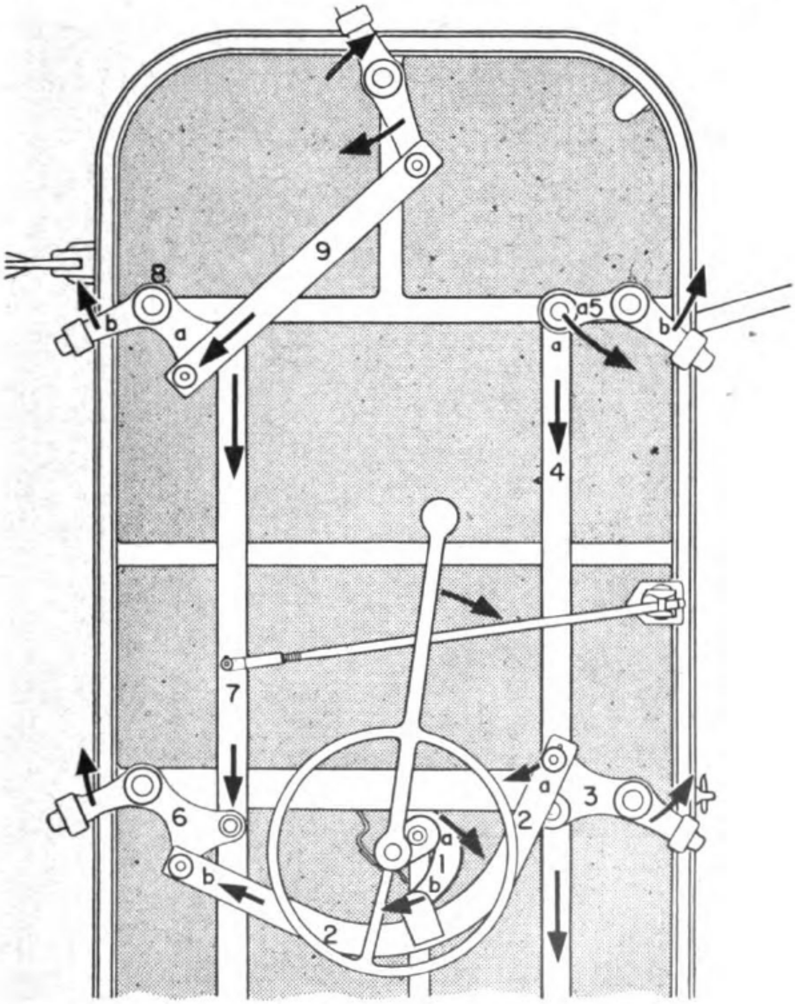



Figure 99.—It works, too.

lever *6* outward and into the locking position, and at the same time causes arm *7* to move downward. This motion causes lever *8* to be swung in a clockwise direction until it too locks. You can see that lever arm *9* follows the movement of *8* and thus causes the dog at the top of the door to swing into the locked position.

Probably, at first glance, this mechanism looked highly complicated. But it isn't so tough to figure out, after all.

## TRY YOUR LUCK

In the following paragraphs, you'll have a chance to figure out the operation of some shipboard machines. The solutions are placed at the end of the chapter so that you can check your answers.

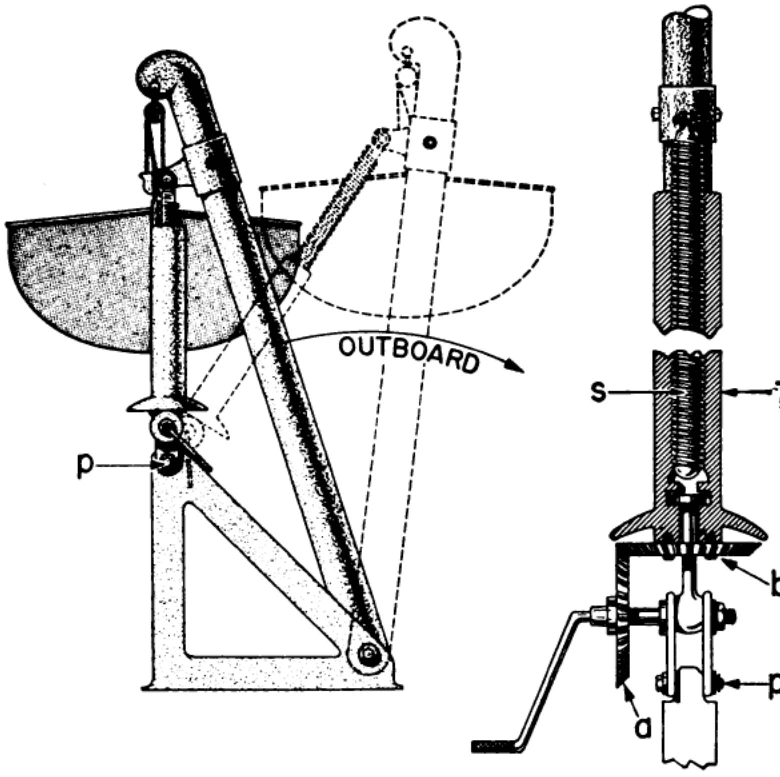



Figure 100.—Wellin life davit.

The WELLIN LIFE DAVIT is a machine for putting life boats over the side. Figure 100*A* gives you an overall view of the apparatus in the inboard position. Figure 100*B* gives you a cut-away view of the operating parts. The bevel gear *a* meshes with bevel gear *b*, which is FIXED to the outer tube *t*. The long screw *S* is attached at its upper end to the arm which supports the life boat. Its thread meshes with those cut on the inner wall of the tube *t*. With that much information, you should be able to figure how the boat is swung out over the side. Try it.

## DEPTH-CHARGE RELEASE MECHANISM

In figure 101 you see the mechanism which releases DEPTH CHARGES over the stern. The rack holds several "ash cans" on sloping rails. When cans are

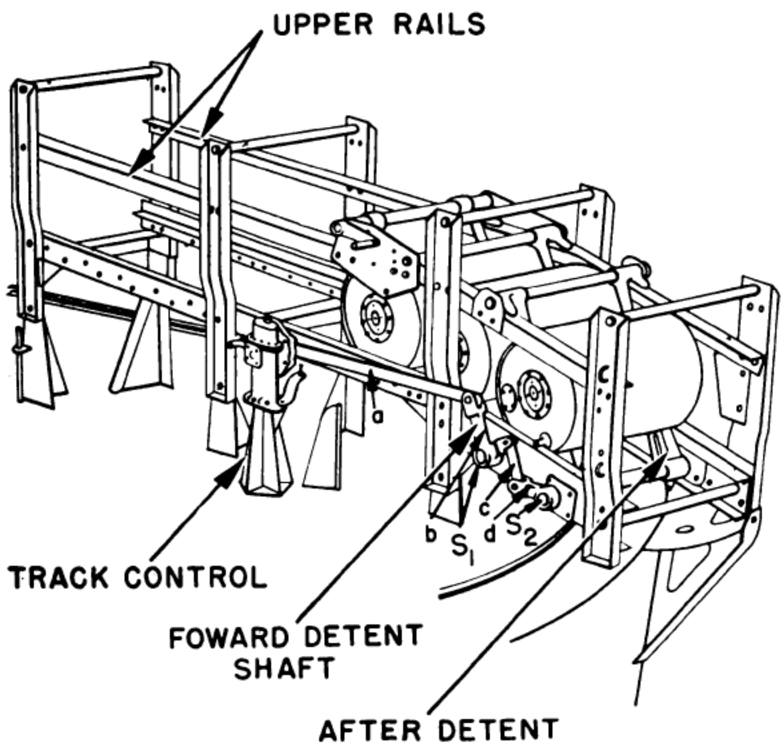



Figure 101.—How you roll out the cans.

to be released, the track control is operated, either by hydraulic-electric gear from the bridge or from the stern control point. When the control button is pressed, arm *a* moves toward the rear, and the AFTER DETENTS drop down counterclockwise to let can No. 1 roll down the track and over the stern. FORWARD DETENTS, which are not shown, prevent the whole rack full of cans from dropping over the stern with one push of the control.

Can you follow the motion from arm *a* through the bell-crank and arms to show how the release gear operates the after detents?

## A FIRE-CONTROL MECHANISM

On a moving ship, aiming a gun at a target which is also on the move—and on a different course into

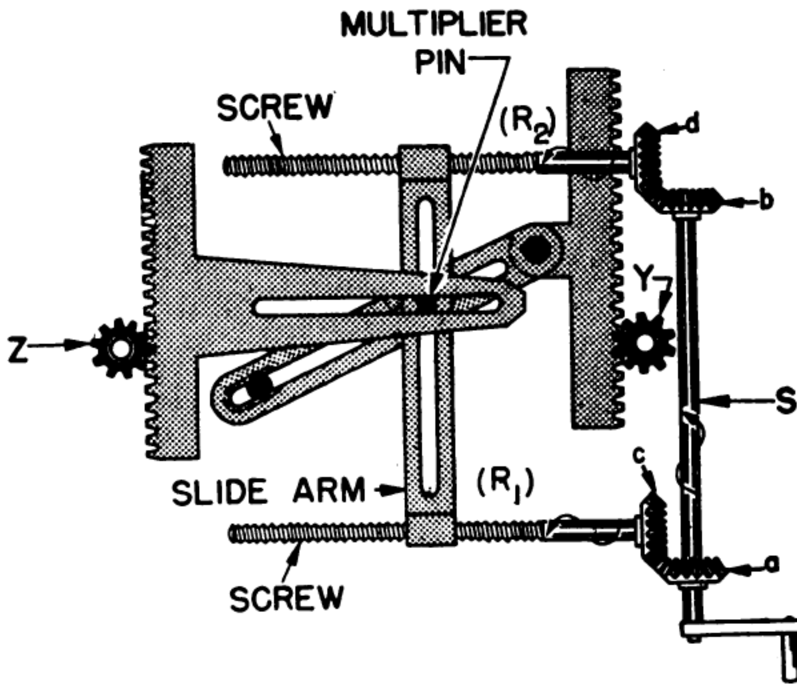



Figure 102.—Watch this one.

the bargain—is a somewhat complicated problem. It used to be done by trial-and-error. Today these fire-control problems are solved by machinery. About all the gunnery officer has to do is to feed the correct figures into the machine. Range, speed of own ship, speed of the target ship, wind speed, are some of the items the gunner needs to know. The machine does the rest of the job for him, and comes out with the proper settings for the guns. While fire-control mechanisms are mighty complex, here is a part of one on which you can get some practice. Suppose that the shaft *S* in Figure 102 is turned in the direction indicated, in what direction will that MULTIPLIER PIN move? In what direction will the pinion $Z$ turn? Assume equal loads on pinions $Y$ and $Z$.

## A TRANSMISSION

If you're all clear up to now, try this final test of your knowledge. You know that a TRANSMISSION is connected to most gasoline engines and that this transmission makes it possible for you to change speeds—change the ratio between engine speed and the speed of the wheels. By shifting the position of the gear-shift lever, you can select any one of several gear speeds. Figure 103 shows you the arrangement of a typical automobile transmission. The gears are shown in neutral, first, second, high, and reverse. Notice that the sliding gears may be shifted along the main shaft—but, because they are keyed on a grooved—SPLINED shaft—shaft, they turn the shaft as they rotate. The drive gear and the speed gears are located on the lower, or counter shaft. Can you follow the transmission of power through the system in each of the four drive positions?

Just to make it a real problem, assume that the pinion gear is turned by the engine at 500 revolutions per minute. The pinion gear has 18 teeth; the drive gear has 30. The second speed gear has 24 teeth, and the forward sliding gear the same number. The aft sliding gear has 30, and the low gear 15. There are 12 teeth on both the reverse gear and the idler. With all that information, can you figure the speeds of the propeller shaft—in revolutions per minute in each of the four drive positions?

## SIGNING OFF

Well, that's about it. If you have understood what you've read, you will have learned the following points about machines in general—

A MACHINE is any device that helps you do WORK. It helps you by changing the MOTION, MAGNITUDE, or SPEED of the effort you apply.

ALL MACHINES consist of one or more of the SIX BASIC MACHINES. The basic machines are the LEVER, the BLOCK AND TACKLE, the WHEEL AND AXLE, the INCLINED PLANE, the SCREW, and GEARS.

When machines give a mechanical advantage of MORE THAN ONE, they MULTIPLY the FORCE of your effort. When they give a mechanical advantage of LESS THAN ONE, they MULTIPLY either the MOTION, or the SPEED of the force you apply.

No machine is 100 per cent efficient. Some of your effort is always used to overcome FRICTION. You always do more work on the machine than it does on the load.

You can figure out how any complex machine works by breaking it down into the simple machines from which it is made, and following the action through, step-by-step.

## ANSWERS TO YOUR PROBLEMS

WELLIN LIFE DAVIT.—Face the handle and turn it in a counterclockwise direction. Then bevel gear *a* will cause gear *b* to revolve in a counterclockwise direction if viewed from below. Tube *t*—being FIXED to gear *b*—moves in a counterclockwise direction and causes the threaded screw to be turned up out of the tube. Notice that the tube is pivoted at *p*. As the screw lengthens, the screw and the tube swing the davit arm outboard—as shown by the dotted lines on figure 99. (That collar on the davit arm does NOT slide along the arm.) Reversing the direction of the handle brings the davit arm inboard.

DEPTH CHARGE RELEASE MECHANISM.—When the operating handle is swung upward, the lever arm *a* moves to the right. The V-shaped lever arm *b* and

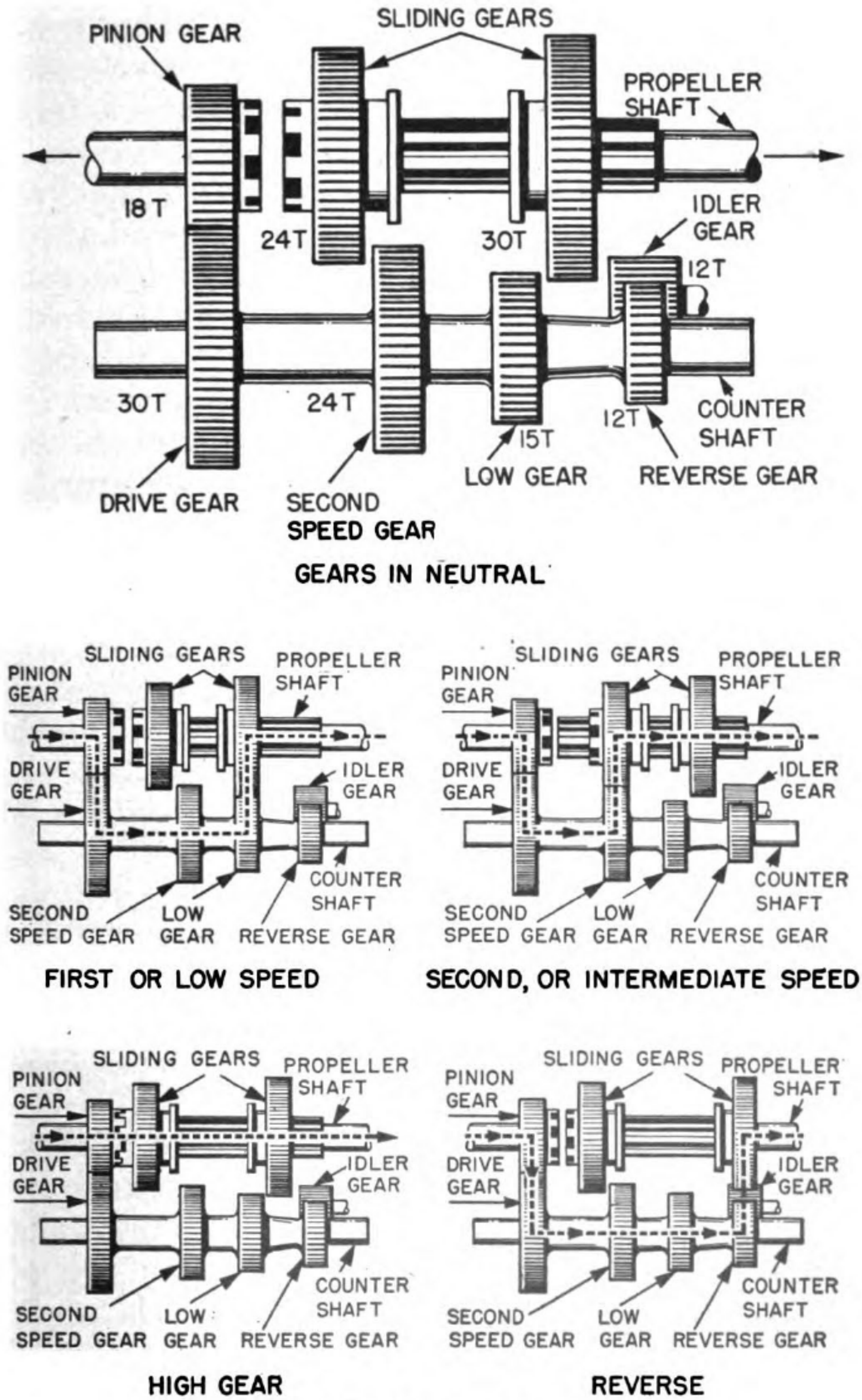



**Figure 103.—Can you figure it out?**

its shaft $s_1$ are rotated clockwise. The forward detent, which is fixed on shaft $s_1$ swings up clockwise in front of the second can on the rack. That's what prevents the whole rackfull from going overboard at once. The clockwise rotation of bell-crank *b* pushes downward on the link *c*. This in turn causes the lever arm *d* and its shaft $s_2$ to turn counterclockwise. The after detent—which is made fast to shaft $f_2$—turns downward to the left, releasing the first can.

Now you can get the next can in position for release. You do this by swinging the operating handle to its original position. This lets "can number two" roll back against the after detent. But how did that after detent get up again? At the same time that *b* moved counterclockwise, link *c* pulled *d* and its attached shaft $s_2$ clockwise. The after detent turns upward and holds the can in position ready for release.

A FIRE-CONTROL MECHANISM.—As the shaft *S* turns counterclockwise, as viewed from its lower end, the bevel gears *a* and *b* also turn counterclockwise. This motion causes the bevel gears *c* and *d* to turn counterclockwise, as viewed from their right. The screws $r_1$ and $r_2$ turn with the gears *c* and *d*—and in the same direction. That motion of the screws will push the slide arm to the left. The multiplier pin will move downward in the diagonal slot. The pinion slide moves downward with the pin and its rack will cause the pinion *Z* to rotate in a clockwise direction.

TRANSMISSION.—Look at the diagram of the transmission in first speed. The power is transmitted from the pinion to the drive gear on the countershaft. The countershaft and its attached gears are now turning. In this position the low gear is meshed with the aft sliding gear. The rotation of this sliding gear causes the propeller shaft to turn with it.

Now for the second-speed diagram. Again the power is transmitted from the pinion to the drive gear. This time, however, the second-speed gear on the countershaft meshes with the forward sliding gear. The rotation of this sliding gear transmits the power to the grooved propeller shaft.

The high-speed diagram is easy. Notice that the forward sliding gear has been pushed far enough forward so that it meshes DIRECTLY with the pinion gear. Power is now transmitted straight through the propeller shaft. The countershaft idles in thisspeed.

The reverse-speed diagram is a little more complicated. The pinion transmits the engine power to the drive gear on the countershaft. The reverse gear on the other end of the countershaft meshes with the idler gear. The idler gear in turn transmits the power to the aft sliding gear which turns the propeller shaft. Remember that the purpose of an IDLER GEAR is to REVERSE the direction of rotation. In this case the propeller shaft is rotated in the opposite or reverse direction.

Now for the speeds of rotation. Start with the first gear diagram. The pinion meshes with the drive gear, and the low gear drives the aft sliding gear. You have two drivers and two driven gears. Use the formula you learned in chapter 6—

$$r=\frac{T_a\times T_c}{T_b\times T_d}$$

$r$ = speed reduction ratio,

$T_a$ and $T_c$ = number of teeth on the wheels which are drivers,

$T_b$ and $T_d$ = number of teeth on the wheels which are driven.

Substitute the proper values—

$$r=\frac{18\times 15}{30\times 30}=\frac{3}{10}$$

If the pinion gear is turning at 500 rpm and the speed reduction ratio is $\frac{3}{10}$, then the speed of the propeller shaft is found by multiplying the original speed by the ratio $\frac{3}{10}\times 500=150$ rpm, the speed of the propeller shaft.

In the second speed diagram the driver gears are the pinion and the second speed gear. The driven gears are the drive gear and forward sliding gear. Substitute these values in the formula to find the speed reduction ratio.

$$r=\frac{18\times 24}{30\times 24}=\frac{3}{5}$$

Now multiply the speed of the pinion gear by this ratio, and you have speed of the propeller shaft in second speed—

$$\tfrac{3}{5}\times 500=300 \text{ rpm}$$

High gear is a cinch. Since the pinion meshes directly with the propeller shaft, the speed of the two is the same—500 rpm.

In the reverse diagram, the pinion and the reverse gear are the drives. (Remember, you NEGLECT the idler gear.) The drive gear and the aft sliding gear are the driven gears. Substitute the number of teeth on each gear in the proper place in the formula.

$$R=\frac{18\times 12}{30\times 30}$$

Multiply the speed of the pinion by this ratio and you have the speed of the propeller shaft—$\frac{6}{25}\times 500=$ 120 rpm.

NOW HEAR THIS!—You'll find! it much easier to work each of these quiz problems if you draw a rough diagram and put on all the values and information that are given you in the problem. That's how the experts ease their work and solve the problems—DRAW THE DIAGRAM FIRST!

How Well Do You Know—

# BASIC MACHINES

# QUIZ

## CHAPTER 1

## LEVERS

1. (*a*). The load on the right-rear wheel of your automobile is 800 pounds. The tire is flat, you have no jack. But you find a ten-foot 2 × 4 and a section of log that will serve as a fulcrum. You weigh 170 pounds. How far aft of the axle would you set the log fulcrum so you could raise the wheel by standing on the end of the 2 × 4? (*b*). What class lever are you using?
2. (*a*). You stack 300 pounds of firebrick on a wheelbarrow. The barrow axle is 1½ feet forward of the firebrick. The barrow handles are 3 feet aft of the firebrick. How many pounds will you have to lift to get the barrow under way? (*b*). What class lever are you using?
3. When the five Marines were raising the American flag over Mount Suribachi on Iwo Jima, the combined weight of the flag, the 25-foot flag pole, and the wind pressure against the flag was 100 pounds. This weight was centered at a point 22 feet from the base of the pole. The five Marines were pulling up on the pole at a point three feet from the base of the pole. (*a*). How much effort did the five have to exert? (*b*). What class lever was the flag-pole?

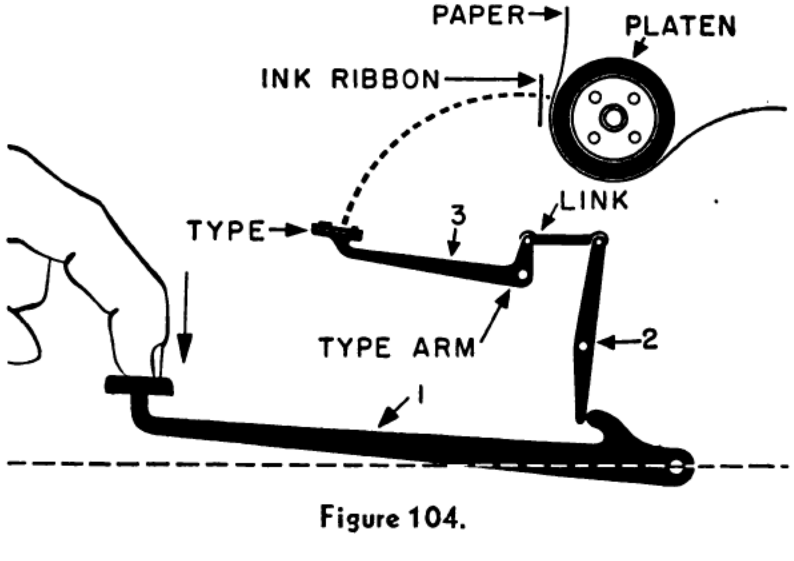



Figure 104.

4. In figure 104 you see the lever system for the type bars of a typewriter. Arm 1 is a __________-class lever. Arm 2 is a __________-class lever. Arm 3 is a __________-class lever.
5. Trace the motion through the mechanisms of figure 103, and put on arrows to show direction of motion when you press down on the key with your finger. Check your diagram with figure —, page —.
6. It takes 4,000 pounds pressure at the cutters to shear a piece of tin plate. Your tin-snips have 18-inch handles and the distance from the hinge-joint to the cutting point is ½ inch. How much pressure must you put on the handles to shear the tin?
7. The handle of a hatch dog is 8 inches long. The short arm is 2½ inches long. You must push down on the handle with how much force to exert 200 pounds force on the end of the short arm? What's the M. A. of this set-up.
8. The ahead turbine steam valve handle is a wheel 24 inches in diameter. (*a*). If it requires 60 foot-pounds to open the valve, how much effort will you have to put into each hand on opposite sides of the wheel? (*b*). How much effort if you pull with only one hand?

## CHAPTER 2

# BLOCK AND TACKLE

1. (*a*) A single fixed pulley is actually a __________-class lever. (*b*) What's its mechanical advantage?
2. (*a*) A single movable pulley is a __________-class lever. (*b*) What's its mechanical advantage?
3. What is the mechanical advantage of the tackle shown in figure 105?
4. Barney has come up with the Goldberg rig shown in figure 106, using three blocks and three falls. Is there any mechanical advantage in this rig? If so, how much?
5. What is the mechanical advantage of a differential chain hoist if the large wheel has a diameter of ten inches and the small wheel has a diameter of nine inches?

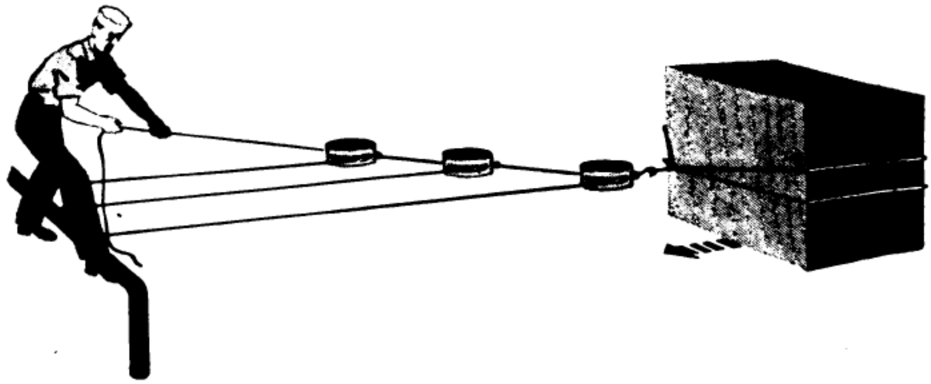


Figure 106.

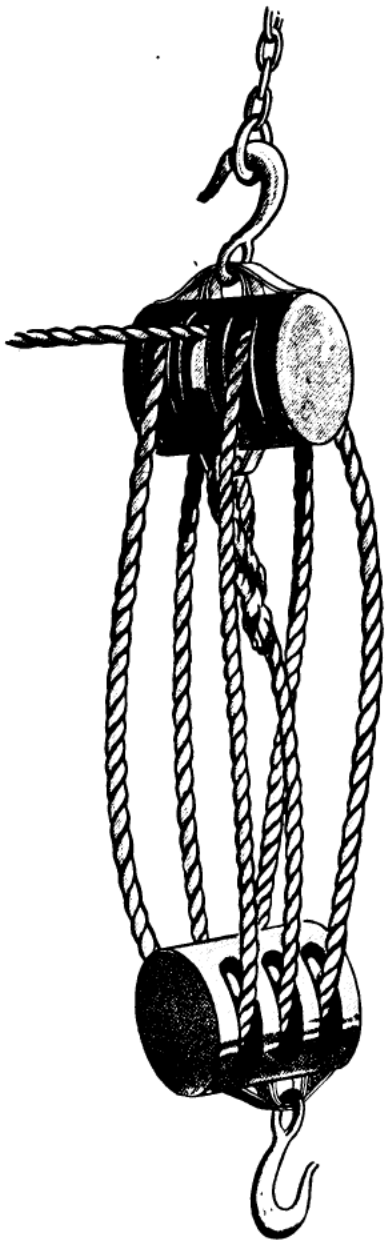


Figure 105.

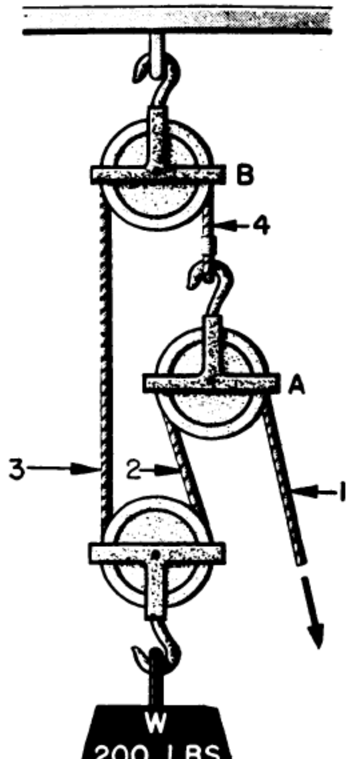



Figure 107.

6. Figure the mechanical advantage of the rig shown in figure 107. (Be careful—this one will fool you!)
7. All by yourself, you're going to hoist a 600-pound piano up to the third-story window of an apartment. You can pull 150 pounds' worth. You have to use a fixed block fastened to the overhanging roof of the building, 36 feet above you. You have a movable block attached to the pad-eye of the piano. (*a*) What mechanical advantage will the blocks and falls require? (*b*) How many sheaves will the fixed block require? (*c*) The movable block? (*d*) Will the bitter end of the fall be fastened to the fixed block or the movable block? (*e*) How many feet of rope will you have to pull to lift the piano 36 feet?

## CHAPTER 3

# WHEEL AND AXLE

1. What maximum load can you lift by applying a 50-pound force to the handle of an 18-inch crank that is connected to the drum of a hand winch? The drum has a DIAMETER of nine inches.
2. You want to start a stuck screw, so need lots of leverage. Would you use a thin-handle screw driver or a fat-handle one? Why?
3. In figure 108, the drive pulley of the electric motor has a diameter of two inches. The large pulley has a diameter of six inches.
   (*a*) What is the M. A. of the large pulley? (*b*) If the motor turns up 1,800 rpm., how many rpm does the large pulley turn?
4. Two men are cranking a windlass to raise a 2,000-pound load. The crank has a two-foot ARM, and the axle is four inches in DIAMETER. (*a*) How much effort must the two men exert? (*b*) What is the M. A. of this rig?
5. The radio dial in figure 109 has an outside diameter of six inches. The inner knob has a diameter of two inches. What's the *M. A.*?
6. You want to tighten a nut on a bolt. The bolt and nut will withstand a twist or torque of 750 inch-pounds without

stripping. Your wrench is twelve inches long from handle to the center of the jaws or to the center of the bolt. (*a*) How much maximum pressure should you put on the wrench handle? (*b*) Barney the Dope decides he can make his work easier by slipping an eight-inch length of pipe over the wrench handle and pulling only 50 pounds worth. How much pull does he put on the nut?

## CHAPTER 4

# INCLINED PLANE

1. A 45-foot gangplank reaches from the dock to a ship's deck 24 feet above the dock. What's the M. A. of the gangplank?
2. You moved a 400-pound crate up an inclined plane 12 feet long to a truck bed three feet above the sidewalk. You know that you pushed 175 pounds worth. (*a*) What was the theoretical M. A. of the inclined plane? (*b*) How much of your push was used up to overcome friction?
3. Instead of working himself into a lather shoving that crate across the deck, Jack has found four lengths of iron pipe and put them under the crate, as in figure 110, to ease his work. He replaced ______________________ friction with ____________________________ friction.
4. As a member of a damage-control party, you use a maul to drive a wedge in behind a shore, and tighten up a damaged bulkhead. The wedge is 16 inches long, and three inches thick at the butt. (*a*) An 80-pound blow on the wedge butt with the maul delivers how many pounds pressure against the faces of the wedge? (*b*) What is the M. A. of the wedge?

## CHAPTER 5

# THE SCREW

1. If you use a screw to get greater mechanical advantage, the screw should have a (small) (large) number of threads per inch. Which?

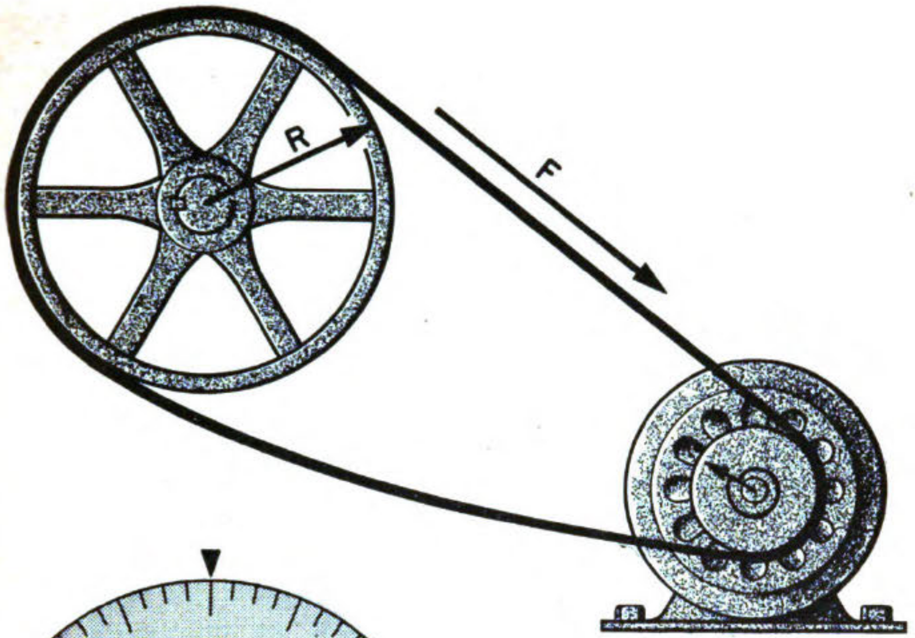



Figure 108.

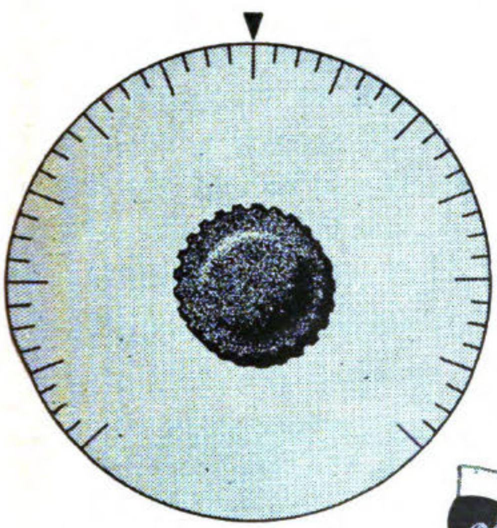
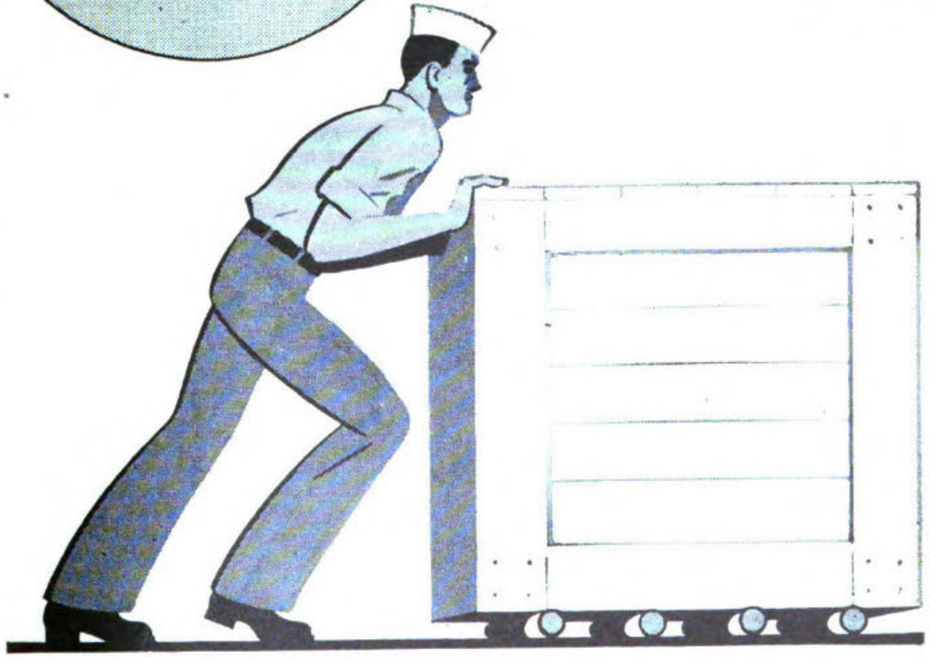


Figure 109.

Figure 110.



2. You use a jack screw to raise a 2,000-pound machine so you can set blocks under it. The jack handle has an effective radius of 24 inches. The pitch of the jack screw is $\frac{3}{16}$ inch. Neglecting friction—(*a*) What's the theoretical M. A. of the jack? (*b*) How much pull do you have to exert? (*c*) How many complete revolutions of the handle will you have to make to raise the machine six inches?
3. If you slide a 12-inch bar half-way through the slot of the turnbuckle in figure 46, page 60, and put 50 pounds turning force on EACH END of the bar, how much force will you put on the cable? Assume a one-inch diameter and a $\frac{1}{4}$-inch pitch for the screws. Ignore friction.
4. The screw on the quadrant davit of figure 55, page 71, is 48 inches long and has five threads to the inch. The crank handle is 24 inches long. To launch a boat, you must crank the traveling nut from one end of the screw to the other. Ignoring friction, (*a*) What is the M. A. of the crank and screw? (*b*) How many feet must the handle of the crank travel in a circular path to launch a boat?

## CHAPTER 6

# GEARS

1. You have a pinion gear with 14 teeth driving a spur gear with 42 teeth. (*a*) The spur gear will turn (faster) (slower) than the pinion. (*b*) What is the M. A.? (*c*) If the pinion turns at 320 rpm., what will be the speed of the spur gear?
2. You use a 20-tooth gear as a driver, turning clockwise. You want this gear to turn a 50-tooth gear in a clockwise direction. There are two ways to arrange this. What are they?
3. Look at the gear train of figure 111. (*a*) Gear *G* will turn (Clockwise) (Counterclockwise). (*b*) The driver gear *A* turns 300 rpm. How many rpm will gear *G* turn? (*c*) What's the M. A. of the train? (*d*) What's the direction of rotation of gear *C*?

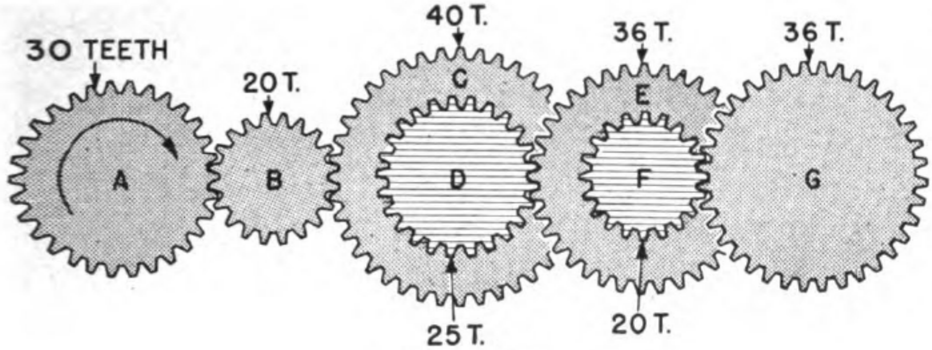


Figure 111.

4. Look at figure 112. (*a*) What is the name for this gear arrangement? (*b*) Worm *A* drives gear *B*. Worm *A* turns 1,200 rpm. Gear *B* has 60 teeth. How fast does gear *B* turn?

## CHAPTER 7

# WORK

1. You weigh 160 pounds. Which would you rather do—climb 50 feet up to the crow's nest, or pull on a fall rove through a single fixed block to raise a 100-pound crate 80 feet. Neglect friction.

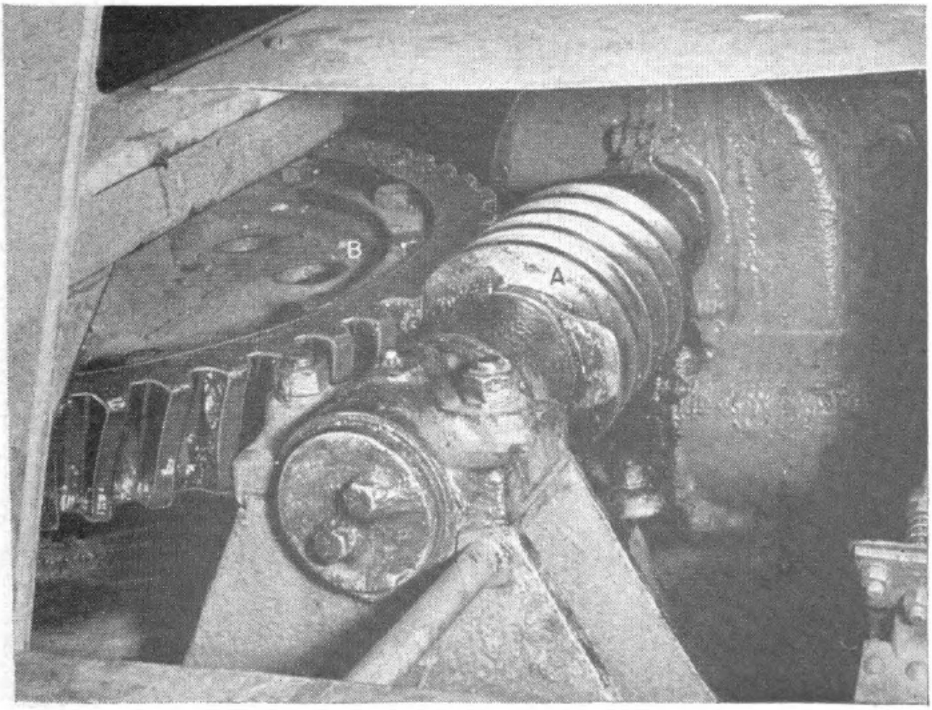


Figure 112.

2. You push 125 pounds worth to slide a 250-pound crate up the gangplank. The gangplank is 12 feet long, and the upper end is five feet above the lower end. (*a*) What is the theoretical M. A. of the gangplank? (*b*) How much of your 125-pound push is used to overcome friction? (*c*) How much is used to overcome gravity? (*d*) What is the efficiency of the gangplank? (*e*) What is the actual M. A. of the gangplank.
3. You want to raise an 1,800-pound motor four feet up to a foundation. You use two double-sheaved blocks and a windlass that has an M. A. of six. Neglect friction. (*a*) How much work do you do to raise the motor? (*b*) How much pull must you exert to raise the motor?
4. A jackscrew has a pitch of ¼ inch and a handle 24 inches long. (*a*) If you neglect friction, how much effort must you use to raise a 40,000-pound railroad car. (*b*) But the jackscrew has an efficiency of only 30%. How many pounds could you lift with the effort of question (*a*)?
5. The hammer of a pile driver weighs 1,000 pounds. The resistance of the earth is 6,000 pounds. If the hammer drops 4 feet to drive a pile, how far into the earth will the pile be driven.

## CHAPTER 8

# POWER

1. An ammunition hoist is powered by a 2–HP motor. Working at full load, and neglecting friction, how long will it take the motor to raise a 54-pound shell 22 feet from the handling room to the gun turret?
2. You use a 25–HP motor to raise a 4,000-pound elevator to a height of 44 feet. (*a*) How much horsepower do you use? (*b*) How long does it take?
3. It takes a 54-pound 5/38 shell 20 seconds to rise to 10,000 feet. How much theoretical horsepower is used. Neglect friction and air resistance.
4. You are using a Prony brake to determine the horsepower of an electric motor. The motor turns 1,720 rpm. The diameter of the motor pulley is four inches. The two

spring scales of the brake read 10 pounds and 4 pounds. How much horsepower is the motor developing?

5. An automobile that weighs 3,000 pounds is climbing a hill that rises 1 foot for each ten feet of roadway. The car is traveling at 30 miles per hour. Neglect friction and wind resistance. How much horsepower is the car using? Remember—30 mph=2,640 feet per minute, on the road.

## CHAPTER 9

# FORCE AND PRESSURE

1. A man is walking across a frozen pond. The ice begins to crack under his weight. You shout to him—"Lie down!" Why will this save him?
2. The air brake cylinder on a railroad car has a DIAMETER of eight inches. The locomotive supplies compressed air to this cylinder at 90 pounds pressure per square inch. How much force is transmitted to the brake shoes when the brakes are applied?
3. A Bourdon gage reads 0 pounds at sea level. (*a*) What is the actual pressure in the gage? (*b*) What is the actual pressure when the gage reads 30 pounds? (*c*) When it reads—10 pounds?

## CHAPTER 10

# HYDROSTATIC MECHANISMS

1. Off the coast of the Philippine Islands is the deepest spot in the world—the famous Mindanao Deep—35,400 feet below the water's surface. What is the pressure on a fish lying on the bottom of Mindanao Deep? Sea water weighs 64 pounds per cubic foot.
2. The unit pressure 23 feet beneath the surface of a one-acre lake is 10 pounds per square inch. What is the unit pressure at the bottom of a tank of water 23 feet high? The tank is 2 feet by 4 feet.
3. To clear a fouled screw, Bill has gone over the side with a bucket over his head, as in figure 113. An air hose runs

from an air pump on deck through a check valve and to a fitting on the bucket. Bill's head is five feet below the water surface. Seawater weighs 64 pounds per cubic foot.

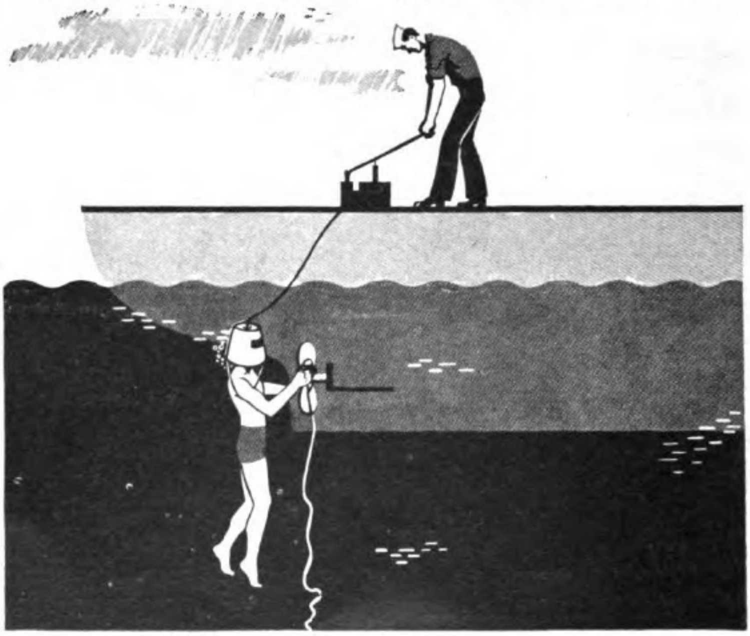


Figure 113.

(*a*) How much pressure must the man on deck maintain in order to equal the pressure at Bill's head? (*b*) If the

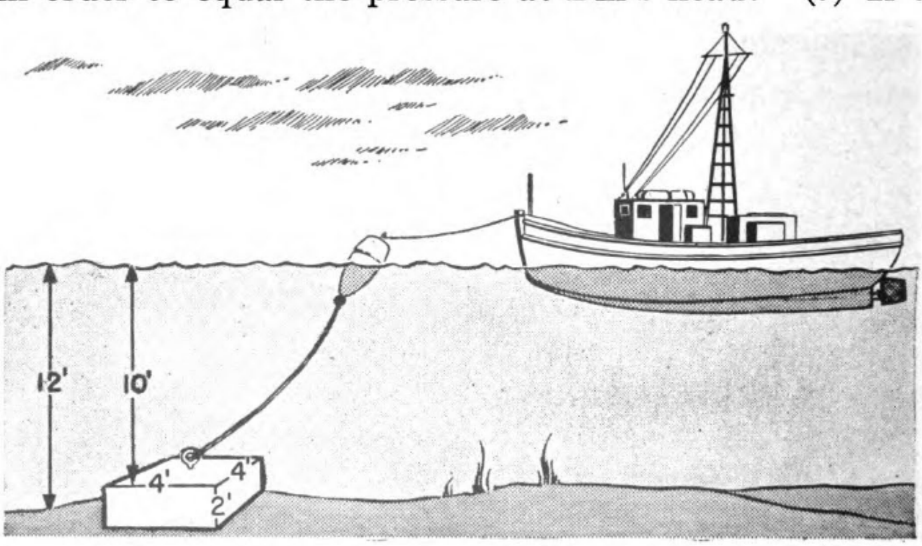



Figure 114.

hose fitting broke at the bucket, what would happen? (*c*) What would happen if there were no straps on the bucket and around Bill's shoulders?

4. Look at the concrete anchor for a mooring buoy in figure 120. The block of concrete is 4′×4′×2′, and its top surface is ten feet below the surface of the water. The anchor lies on a porous sandy bottom, so that water pressure also acts on the under side of the anchor. (*a*) How much force pushes the anchor down? (*b*) How much pushes it up? (*c*) Why doesn't the anchor, which weighs 4,800 pounds, rise to the surface under this upward pressure?

## CHAPTER 11

# HYDRAULIC MACHINES

1. Pressure is the (total load on the total area) (the load per square unit of area). Force is the (total load on the total area) (the load per square unit of area.)
2. Hydraulic systems are based on the principle that liquids are (compressible) (non-compressible).
3. Look at the hydraulic press in figure 91. A 25-pound effort is applied to the handle 15 inches from the fulcrum. The small piston is connected to the pump handle three inches from the fulcrum. The diameter of the small piston is 1½ inches, the diameter of the large piston is 30 inches. How much force is exerted on the large piston?

# ANSWERS TO QUIZ

## CHAPTER 1

## LEVERS

1. (*a*) Since the 2×4 is 10 feet long, let the distance from the axle to the fulcrum be $X$. Then the distance from the fulcrum to your feet will be $10-X$. So—

$$170\ (10-X)=800\ X$$
$$X=1\tfrac{3}{4}\text{ ft.}$$

   (*b*) First-class lever.
2. (*a*) 100 pounds. (*b*) Second-class lever.
3. (*a*) 733 pounds. (*b*) Third-class lever.
4. First-class. Second-class. Third-class.
5. Answer:

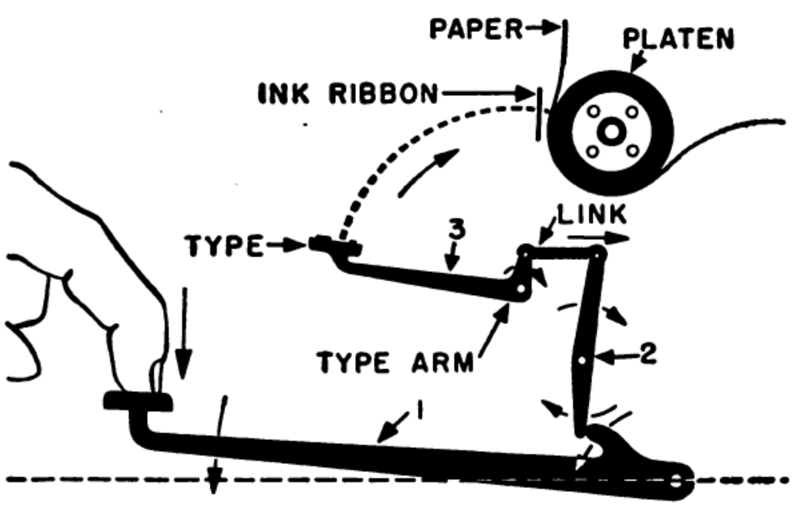



Figure 115.

6. 111 pounds.
7. (*a*) 62.5 pounds; (*b*) 3.2.
8. (*a*) 30 pounds. (*b*) 60 pounds.

## CHAPTER 2

## BLOCK AND TACKLE

1. (*a*) First-class lever. (*b*) One.
2. (*a*) Second-class lever. (*b*) Two.
3. Six.

4. Yes. Eight to one.
5. Twenty to one.
6. That's right. The mechanical advantage is ZERO. In fact, this rig is called the "Fool's Tackle" because it won't work. The load on parts 2 and 3 is 100 pounds each. The load on part 4 is 100 pounds. If part 2 has 100 pounds on it, part 1 must be pulled down with 100 pounds. So, Block A has 100 pounds up-pull on it in part 4, but has 200 pounds down-pull in parts 1 and 2. So you'd get rapped over the head if you tried to use the Fool's Tackle.
7. (*a*) Four to one, (*b*) Two sheaves, (*c*) Two sheaves, (*d*) Movable block, (*e*) 144 feet.

## CHAPTER 3

# WHEEL AND AXLE

1. 200 pounds. Remember the RADIUS of the drum is half the diameter.
2. Fat-handle screw driver, because its moment-arm would be greater, hence its M. A. would be greater.
3. (*a*) Three to one; (*b*) 600 rpm.
4. (*a*) 167 pounds; (*b*) Twelve to one.
5. Three to one.
6. (*a*) 62.5 pounds. (*b*) 1000 inch-pounds.

## CHAPTER 4

# INCLINED PLANE

1. 1.87 to one.
2. (*a*) Four to one; (*b*) 75 pounds.
3. Sliding friction with rolling friction.
4. (*a*) 427 pounds; (*b*) 5.33 to one.

## CHAPTER 5

# THE SCREW

1. LARGE number of threads.
2. (*a*) 800 to one; (*b*) 25 pounds; (*c*) 32 turns.

3. 90,600 lb. (Here's how—

$$\text{M. A.}=\frac{2\pi r}{p}=\frac{2\pi\times 6}{1/4}=151$$

Then the bar gives a COUPLE, which is

$$F=50\#\times 12''=600 \text{ inch-pounds,}$$

and

$$F\times MA=600\times 151=90{,}600 \text{ inch-pounds.}$$

4. (*a*) $\text{M. A.}=\frac{2\pi r}{p}=\frac{2\pi\times 24}{1/5}=754$

(*b*) Length of path$=48\times 754=36{,}150$ inches
$=3{,}014$ feet.

## CHAPTER 6

# GEARS

1. (*a*) Slower; (*b*) Three; (*c*) 140 rpm.
2. (*1*) Use an idler gear, or (*2*) make the 50-tooth gear an INTERNAL gear.
3. (*a*) Clockwise.

(*b*)
$$S_G=S_A\times\frac{T_a}{T_c}\times\frac{T_d}{T_e}\times\frac{T_f}{T_g}$$

$$=300\times\frac{30\times 25\times 20}{40\times 36\times 36}=87 \text{ rpm.}$$

(*c*) $MA=\frac{300}{87}=3.45$ to one.

(*d*) Clockwise.

4. (*a*) Worm and wheel.

(*b*) $S_B=\frac{S_A\times T_A}{T_B}=\frac{1200\times 1}{60}=20$ rpm.

# CHAPTER 7

# WORK

1. Take your choice. In each case you're doing 8,000 foot-pounds of work.

2. (*a*) T. M. A. $=\frac{12}{5}=2.4$ to one.

   (*b*) $E_G=\frac{250}{2.4}=104\#$ to overcome gravity.

   (*c*) $E_F=125-104=21\#$ to overcome friction.

   (*d*) Efficiency $=\frac{104}{125}=0.833=83.3\%$.

   (*e*) Actual M. A. $=\frac{12}{5}\times 0.833=2$ to 1.

3. (*a*) $1{,}800\times 4=7{,}200$ foot-pounds.

   (*b*) $\frac{1{,}800}{4\times 6}=75\#$, since the M. A. of the blocks and tackle is four and the M. A. of the winch is six.

4. (*a*) M. A. $=604$, and $E=\frac{40{,}000}{604}=66.3\#$ effort.

   (*b*) 12,000#, since $604\times 0.30\times 66.3=12{,}000\#$.

5. $\frac{4\times 1{,}000}{6{,}000}=0.667$ ft.

# CHAPTER 8

# POWER

1. $\frac{54\times 22}{2\times 550}=1.08$ seconds.

2. (*a*) $\frac{4{,}000\times 44}{33{,}000}=5.33$ hp. to raise the load.

(*b*) $\frac{4,000\times 44}{25\times 550}=2.13$ seconds to raise the load.

3. Forty-nine horsepower.

4. Motor develops 3.925 hp.

5. 24 horsepower. Here's how—the automobile moves straight upward one foot for every ten it moves along the road or $2,640\div 10=264$ feet per minute. So—

$$\frac{3,000\times 264}{33,000}=24 \text{ hp.}$$

## CHAPTER 9

# FORCE AND PRESSURE

1. It distributes his weight over a larger area of ice, thereby reducing the pressure per square inch on the ice.

2. $A=\frac{\pi d^2}{4}=\frac{\pi (8)^2}{4}=50.2$ sq. inches of piston.

   $P=50.2\times 90=4,520$ pounds.

3. (*a*) 14.7 pounds.

   (*b*) $14.7+30=44.7$ pounds

   (*c*) $14.7-10=4.7$ pounds.

## CHAPTER 10

# HYDROSTATIC MACHINES

1. 2,265,000 pounds per square foot, or 15,730 psi.
2. The same—the size of the body of water has nothing to do with the unit pressure. Depth determines unit pressure.
3. (*a*) $\frac{5\times 64}{144}=2.22$ psi.

   (*b*) The pressure of the water would force the air out of the bucket.

   (*c*) The air in the bucket would float it to the surface.

4. (*a*) 10,240 pounds.
   (*b*) 12,288 pounds.
   (*c*) The pull of gravity—4,800 pounds—on the anchor is greater than the difference in pressures (*a*) and (*b*)—12,288 − 10,240 = 2,048 pounds.

## CHAPTER 11

# HYDRAULIC MACHINES

1. Pressure is the load per square unit of area. Force is the total load on the total area.
2. Non-compressible.
3. 50,000 pounds.

# INDEX

○

## Please . . .

Take good care of this training course. It is only loaned to you. When you have completed the course, return it to your Educational or Divisional Officer for reissue. This book must be reissued until it becomes unfit for further use. If the Navy is to continue issuing sufficient training courses to meet the increased demands of its enlisted personnel, it must exercise the strictest economy in the use of its books. Please cooperate!